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## **Development of a heuristics-based method as a support tool for the design process**

GRADUATION MANUSCRIPT PRESENTED AS PARTIAL REQUIREMENT TO OBTAIN THE  
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# Abstract

This document compiles the development and validation of a research process focused on evaluating the applicability of heuristic rules into the decision-making processes involved in design practices. The goal of the present study is to generate a strategic approach for the fixation, tangibilization and reuse of knowledge within environments usually involved in design processes. For this purpose, the research focuses on the proposition of a method that seeks to facilitate the introduction of heuristics into particular stages of the design process, such as conceptualization and architecture definition. This is achieved by providing a structured approach that involves a disaggregation of the design problem, and its further analysis towards the definition of specific problem solving actions based on heuristic rules.

Furthermore, this study comprises the development of a specific tool that helps designers implement heuristic strategies in their design problems by exemplifying said strategies and generalizing the physical or mechanical principle behind them.

In general terms, what is expected of this research is that the defined method and its support tool will help designers to explore diverse solution principles with applications previously implemented in diverse domains, thus triggering creativity in decision-making and problem solving activities. This will enable a more diverse and detailed concept generation activity. In addition, it will allow organizations to count with tools and procedures for them to ensure that emerging knowledge can be integrated to the proposed approach and reused in the future.

**Keywords:** Heuristics, design methodology, decision-making, product design.



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# Chapter 1

## Introduction

### 1.1 Problem definition

Every design process in general is, in itself, a problem solving process [Simon, 1996]. Specifically, design processes that are oriented towards product development, aim to give tangible technical solutions to situations that demand the creation of artifacts or systems for the satisfaction of certain needs. This particular aspect of design, namely that of intending to solve human needs from a technical perspective, is precisely what defines design practices as problem solving activities.

Different stages of the design process face design engineers with problem solving situations that conduct them towards making decisions that can alter the course of a design project, regardless of its nature. Among these stages, processes such as product architecture definition, conceptualization and concept evaluation stand out because of the relevance and impact that the decisions made can have in the overall workflow and particular outcomes of a project.

Furthermore, the decisions that aim to solve design issues in any particular stage of the process are often of iterative nature [Roozenburg and Eekels, 1995] and are made under conditions of uncertainty [Beheshti, 1993]. Ultimately, the choices made end up restraining or altering the possibilities of a design process in terms of technical and conceptual direction. As a matter of fact, it is known that any choice in early stages of the design process has indeed a direct impact in the cost of the product lifecycle, accounting for as much as 80% of said costs. [Smith and Reinertsen, 1998].

Which of the concepts best embodies the initial requirements? How to solve the technical

contradictions that arise from conflicting requirements? Is there a more straightforward way to approach a particular solution?

In environments where design practice is habitual, such as enterprises, R+D areas and academic surroundings, it is expected to encounter, whether tangible or not, existing knowledge regarding the most appropriate way to respond to these and other specific questions related to design problems. The answer to such questions is generally based upon praxis and experience that has been obtained by individuals and organizations when giving solutions to similar problems in a systematic manner. However, how can an organization ensure that the answers that are already known will be readily available in the future for the resolution of a similar problem?

Knowledge, understood as intellectual capital, is extremely valuable for design-oriented organizations, because it holds a great part of their know-how. In other words, what an organization knows, particularly when it comes to design, is proof of what the people in it have learned over a period of time. The experience that gives rise to such knowledge, although manifested implicitly in the reiterated implementation of processes and solution principles, in some cases is not consolidated at the inside of the working environment in the shape of structured knowledge. This means that knowledge is effectively there, but lies intangible.

The problem is precisely rooted in the fact that, when the design outcomes are drawn from a non-structured process, there is a certain risk that the knowledge generated from practice and experience will not be of use for the organization in the future, because there is no effective or structured way to access it. Consequently, it is important to count with methods and tools that guarantee the permanence of knowledge within organizations, thus allowing its utilization in future occasions. The value of making an effort towards the understanding, consolidation and structuring of knowledge being generated through the execution of design processes, is that it eventually enables the solution of design problems in a more effective way; specifically because counting with methodological strategies that enable the design engineer to consciously employ resources that have been previously used in other situations, will conduce towards attaining new design solutions in a more direct manner.

This is the fundamental purpose of heuristics: to create a structure for existing knowledge from different domains in order to ensure a logical route for its reuse in the future.

The positive implications of said approach are reflected not only in the time and cost

reduction during project execution, but also in the conceptualization process in itself, given that the usage of heuristic strategies might enhance the diversification of design alternatives and strengthens conceptual exploration by providing more detailed concepts in early stages of the process.

The purpose of this study is, therefore, to explore how heuristics can be used within design processes and what benefit can be derived from such implementation.

## 1.2 Research questions

The context provided by the problem definition points at a clear direction in terms of the value of conducting a research focused on the incorporation of heuristics in the design process. Therefore, in order to establish a clear research direction, the following research questions have been set.

- Is it possible to create, through design heuristics, a knowledge structure based in theoretical concepts and industrial experience?
- What is the impact of implementing heuristic rules in the design process?

The purpose of the present document is to give insights on how to resolve them through the proposed approach.

## 1.3 Objectives

### 1.3.1 General objective

To develop a support tool for the product development process, based upon a heuristic approach, which enables the use of previous experiences as an input argument for the resolution of design problems.

### 1.3.2 Specific objectives

- To identify and explore the background and leader authors in the field of design heuristics.
- To create and structure a knowledge base supported in heuristic rules.

- To develop an approach that helps design engineers to incorporate heuristic rules into their habitual design processes.
- To develop a platform for the implementation of the approach.
- To validate in practice the proposed heuristics structure, along with the development and usability of the support tool.
- To carry on a knowledge transfer procedure that enables the implementation of the developed tool in the future.

## 1.4 Research Scope

The scope of the present project aims to develop and test a heuristics-based approach created upon the basis of an existing knowledge base, that will serve as support for design engineers and product developers in their creative processes. In this sense, the deliverable of the research is not only a methodological approach, but also a web based software tool that will make tangible the integration of heuristics into the design process.

## 1.5 Research methodology

The present research was carried out following an approach described by Horváth as *Design in Research Context*, or DiRC [Horváth et al., 2007]. This specific approach is closely related to the fundamental Scientific Research method, with the particularity that DiRC is oriented towards the understanding of design issues in specified contextual circumstances. (See Figure 1.1)

This context that frames DiRC is determined, in general, by three elements: (a) User, (b) Artifact and (c) Environment. The interactions between these elements characterize a design phenomenon that can be subject of research, and the understanding of these interactions and their relationship with the set research variables is precisely the goal of said research

It is important to state that this methodology can deal with a variety of design problems, ranging from the very specific engineering-related applications to conceptual and methodological interests.

In this particular case, the research methodology is configured as follows:

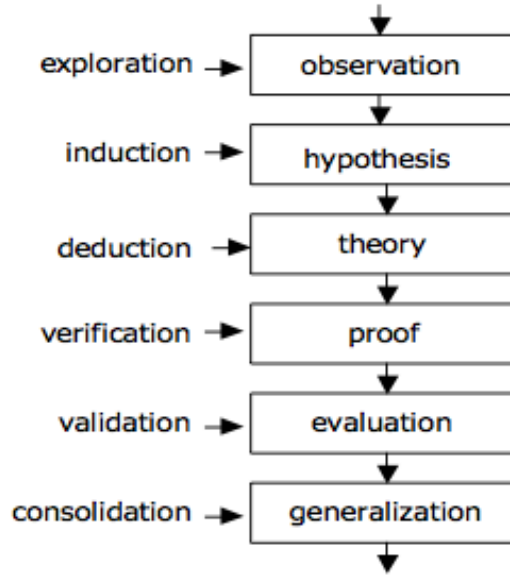


Figure 1.1: DiRC approach

- **Observation:** Study of the background and state of the art in the research field, and determination of the potential for the application of heuristics in design.
- **Hypothesis:** Proposition of a methodological approach for the integration of design heuristics in the product development process.
- **Proof:** Validation of the proposed design approach in applied case studies.
- **Evaluation:** Analysis of the validation results.
- **Generalization:** Establishment and documentation of a particular method and tool for the implementation of design-specific heuristic rules into the product development process.

As a result, the methodological approach will enable the construction of a new approach based on the hypothesis that it will generate positive impacts in the design process; said approach will be validated and generalized through design exercises.

## 1.6 Manuscript structure

The first chapter approaches the research objectives and questions that guide the study compiled in this document, as well as the scope of the research and the methodology followed



towards the pursuit of the results. The second chapter describes the prior literature related to the research topic, including approaches in design methodology, different methods related to knowledge reuse and the specific application of heuristics in design. The third chapter offers a guide to the technical and theoretical concepts involved in the research subject that are the basis for the construction of the methodological approach proposed in this research. Particularly, it explores the integration of heuristics in design processes, the construction of the heuristic rules that are taken as a reference, and the proposition of specific tools as a support –both existing and developed specifically in this research– for the application of heuristics in design practices. Chapter Four gives an in-depth view of the proposed method, offering a step-by-step view of the suggested approach. Chapter Five describes the testing and validation process followed in a number of case studies with the previously described methodology, and gives insights related to the results obtained with the validation process. Finally, Chapter Six compiles the conclusions of the research and proposes further development areas.

## Chapter 2

# Literature Review

### 2.1 Theoretical Framework

#### 2.1.1 Design Theory and Methodology

The field of design studies that focuses on the understanding and development of procedures followed by product design is known as Design Theory, widely known as DTM.

Design theory deals with the study and proposition of both models and methods that aid designers in carrying out design tasks in a more effective, structured manner. More precisely, design methodology is the "science of methods that can be applied in designing". [Roozenburg and Eekels, 1995]

There are numerous structured approaches developed created with the goal of contributing to the formulation of strategic approaches for product design: Axiomatic Design [Suh, 1990], Robust Design [Taguchi and Clausing, 1990] and Design Thinking [Brown et al., 2008], just to mention a few. All of these authors have sought to envision and communicate a methodological approach that structures the creative procedure of generating new products.

Axiomatic design, for instance, provides tools for the analysis and transformation of user needs into functional inputs for the design process. Robust design is focused on providing methods to ensure that a product preserves its quality regardless of external or internal factors in the production process. Design thinking, on the other hand, is related to the structuring of creative processes for the development of innovative products.

In general, all of these approaches seek one single goal: Provide a set of guidelines that can help designers and engineers make decisions related to specific design problems throughout

the product development process.

However, it becomes apparent that there is a shortcoming in these methods regarding the recollection of experiences resulting from the implementation of said approaches. In other words, these methods serve well the purpose of providing strategies for solving design problems. But how do they ensure that the knowledge emerged from the selection of a particular solution can be preserved and further retrieved in the future so designers can implement it again when applicable?

As a matter of fact, studies have shown that companies do not widely reuse the knowledge generated within themselves: Only 28% of manufacturing firms find ways to reuse their own knowledge in their processes [Ettlie and Kubarek, 2008].

### 2.1.2 Knowledge and experience management

The particularity related to low percentages of knowledge reuse poses an important question: Is the lack of knowledge reuse derived from the absence of adequate methods for knowledge storage and retrieval? The answer to this question is somewhat explored by different approaches that are focused in knowledge and experience management within organizations.

Some of the aforementioned approaches worth noting are Knowledge Based Engineering [Studer et al., 1998][Sandberg, 2003]; Causal Design Knowledge [Kim and Kim, 2011], Process Data Warehouse [Brandt et al., 2008] and other tools of Computer Aided Design and Innovation in general, among others.

Knowledge Based Engineering (KBE), for instance, is based upon the implementation of "advanced software techniques to capture and reuse product and process knowledge" [Stokes et al., 2001].

Causal Design Knowledge, as presented by the authors, is an approach based on the capture of design issues for particular solutions and their probable causes through the combination of Bayesian Belief Networks (BBN) and Fuzzy Cognitive Maps (FCM).

Process Data Warehousing, on the other hand, proposes an approach for the capture and reuse of knowledge through ontologies, understood as conceptual representations of entities and their relations.

What is relevant to discuss from the previously mentioned and any design knowledge management method is that all of them, as well as any design method is based upon a

heuristic structure [Roozenburg and Eekels, 1995], in the sense that design methods help in the process of identifying a solution for a given problem, but they can not guarantee that the solution will be effectively found.

Consequently, it is important to understand the heuristic nature of methodological procedures focused in design knowledge, in order to develop adequate supporting tools for the design process. In this sense, a more detailed exploration of the integration of a heuristics-based approach with the methodological guidelines proposed by conventional design methods will be given in Chapter 3.

### 2.1.3 Heuristics

It has been mentioned that design processes in general, and support tools in particular, have a heuristic nature. So, what exactly are heuristics?

By definition, heuristics refer to the proceedings or approaches that enable someone to reach a solution for a particular problem through the implementation of a "rule of thumb", derived from experience rather than an exhaustive process.

It is defined "as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods" [Merriam-Webster, 2014]. In the design context, they refer to technical or conceptual solutions which implementation has been previously applied and proven in another domain or context, but which can be extrapolated to similar design problems. In this sense, the application of heuristics into design, which is the subject that concerns the present research, offers a particularly interesting view on the design process, due to the fact that it highlights the value of existing knowledge for the solution of problems.

## 2.2 Application of Heuristics in Design

Heuristics, understood as cognitive tools that help to make knowledge tangible and enable its reuse in diverse problem-solving situations, have an interesting value when it comes to envisioning problem solving strategies. For this reason, the use of heuristics in design has been approached in the past as a means of aiding designers and organizations to make the best out of existing knowledge, in order to streamline design processes.

In fact, some studies and tools have been developed in the field of the implementation of heuristics in the product design process.

The following is a review of the most relevant researches and works related to the use of heuristics in design.

## 2.2.1 Developments in Knowledge Theory

### 2.2.1.1 Scamper and Synectics

Some of the first approximations to the use of heuristics in design, such as Synectics [Gordon, 1961] and SCAMPER [Eberle, 1972], emerged from the field of the theory of learning, and were implemented afterwards as creativity tools for the design processes.

**Scamper:** SCAMPER is an acronym for a set of 7 heuristics with which it is intended to explore new possibilities around problem solving. The proposed strategies are: Substitute, combine, adapt, modify, put to a different use, eliminate and rearrange.

In the field of design, particularly, the problem solving strategies are related to the ideation stage. Its purpose is to generate new alternatives from the reconfiguration –architectonic reconfiguration, in the design context– of existing solutions.

In this sense, the goal of this tool is to provide designers with a general concept that can help in the process of envisioning solution strategies to particular problems.

**Synectics:** Synectics, on the other hand, is based upon the use of a structured approach in order to generate strategies that enhance creativity. This approach resulted from the observation of groups interacting in creative processes focused on problem solving. This observation led to the formulation of a procedure that guides groups and individuals from the framing of a problem all the way to the identification of solutions. The key of the work presented by Gordon and Prince lies on the fact that it proposes groups to consider developmental thinking, metaphors and ambiguity, in order to explore a wider spectrum of solutions.

It was born within psychology and behavioral sciences, but since then it has migrated to diverse application areas as did Scamper, and has been applied to product design in the ideation stage, where the priority is the need to diversify the results in the concept generation process.

### 2.2.1.2 Case Based Reasoning

Another development derived from knowledge areas different from design, is CBR (Case Based Reasoning) [Kolodner, 1993]. CBR, understood fundamentally as a cognitive process, is a reasoning strategy that draws upon previous solutions to explain, interpret or solve current problems.

The implementation of CBR approaches demands two main capabilities in order to successfully solve any particular problem:

- **Indexing:** The possibility to assign tags or labels that provide a structure to the existing knowledge.
- **Retrieval:** The ability to recall the previous knowledge based on the indexing strategies, and to identify ways in which previous problem-solving situations can help to solve current ones.

Consequently, the existence of a knowledge base is required as a starting point for problem solving, as well as a series of strategies that enable the adequate recognition and interpretation of the functional element of previous solutions that are applicable to the current problem.

## 2.2.2 Heuristics in design

The previously described strategies and approaches offer, without a doubt, the possibility of obtaining diversity within creative processes of all sorts. However, being tools derived from other areas of knowledge, their specificity in the application on design cases is limited, particularly because elements such as the language used are not design-specific.

To solve this limitation, several authors have explored the possibility of developing design-specific heuristic-based methods. The most relevant works will be cited in this section.

### 2.2.2.1 Design heuristics

The work of Daly and Yilmaz [Daly et al., 2012] seeks to solve to a certain extent the limitations spotted in the previously exposed tools. His studies, supported in the analysis of case studies with design experts and students, are oriented towards the identification of common strategies related specifically to product design, used during the conceptualization stage. The

result of his research is a set of 77 heuristics compiled under the name "Design Heuristics", which, according to his analyses, facilitate the generation and diversification of concepts in practice.

These heuristic rules are presented in the shape of a set of cards (See Figure 2.1) that describe the concept with the goal of inducing designers to consider new or unexplored solutions.

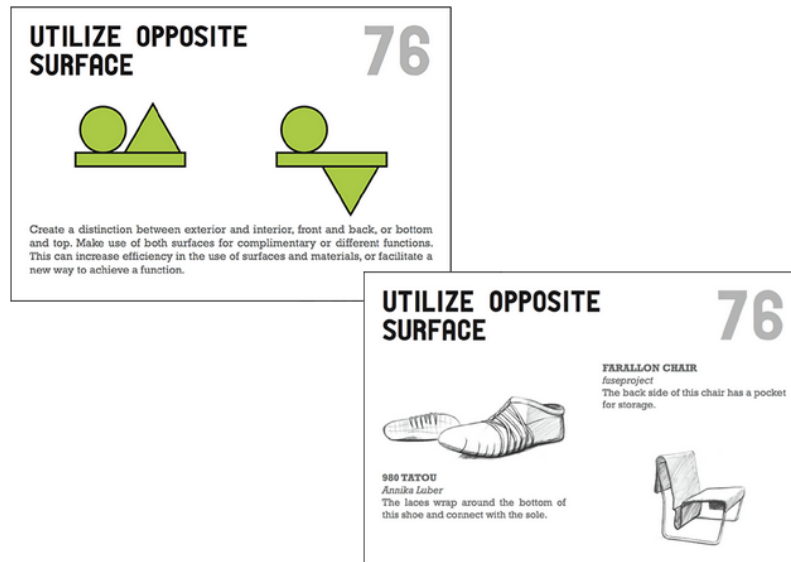


Figure 2.1: Design Heuristics [Daly et al., 2012]

The particular applicability of the tool developed by the authors is focused on the ideation stages of the design, therefore being of limited use throughout the entire process.

#### 2.2.2.2 Heuristics for modular design

Another work worth noting is the one developed by Stone [Stone et al., 2000], in which heuristics are proposed for the identification of possible modular configurations during conceptualization.

The methodology demands the establishment of a detailed functional structure of the product. At this point, the procedure is guided by the identification of three heuristics:

- The identification of the dominant flow, which remains unchanged and constant throughout the functional structure.

- The identification of branching flows, meaning, those that disaggregate into multiple, parallel blocks of functions.
- Identification of conversion-transmission modules, which is where flows experiment a transformation.

The methodology establishes that each of these levels serve as a guideline for the identification of a potential module, therefore conducting to the development of a modular product architecture.

### 2.2.2.3 TRIZ and ARIZ

Another development of similar nature, but with a stronger orientation towards the solution of technical problems, is TRIZ [Altshuller et al., 1998], which in Russian stands for "Theory of Inventive Problem Solving". This approach, along with its methodological implementation –ARIZ (Algorithm to Solve an Inventive Problem) [Altshuller, 1999]– is one of the most widespread tools in the field of design. It is a development which most relevant strength is the extensive knowledge base upon which it is built, created from the analysis and categorization of over 40.000 patented technical solutions, later extended to over 400.000 patents from elsewhere in the subsequent years.

The author's work, derived from the analysis of these patents, is based upon the concept that systems might reach five levels of innovation. The first level, which contains around 30% of the patented solutions, refers to systems that present very little change in relation to previous inventions, if any at all. In level 2, that contains 55% of the evaluated patents, the changes implemented to the solutions belong to the same technological branch. Solutions in level 3, that represent 10% of the existing patents, begin displaying notorious changes to technological systems, including solution principles that come from diverse domains. Solutions in level 4 implement major changes in product development, and come from the better understanding of physical principles that generate conflicts within a system. These represent 4% of the patented solutions. And finally, solutions included in level 5 are those that represent radical innovations, meaning, solution alternatives without scientific precedent. These only represent 1% of all the patented systems.

Altshuller's first proposition, after determining the levels of innovation found in his analysis, is that technical systems follow a number of evolution laws over time (eight in total).



However, the development of technical systems with the purpose of solving a problem eventually poses what Altshuller calls technical contradictions, namely, the existence of conflicting requirements that are mandatory in the conception of a system.

For the solution of said contradictions, the author proposes set of 40 Inventive Principles (See Figure 2.2), that offer particular strategies to attack the detected contradictions.

<div> <div>Undesired Result (Conflict)</div> <div>Feature to Improve</div> </div>		14	15	16	17	18	19	20	21	22	23	24	25	26
		Strength	Durability of moving object	Durability of non-moving object	Temperature	Brightness	Energy spent by moving object	Energy spent by non-moving object	Power	Waste of energy	Waste of substance	Loss of information	Waste of time	Amount of substance
1	Weight of moving object	28,27, 18,40	5,34, 31,35		6,20, 4,38	19,1, 32	35,12, 34,31		12,36, 18,31	6, 2, 34,19	5,35, 3,31	10,24, 35	10,35, 20,28	3,26, 18,31
2	Weight of non-moving object	28,2, 10,27		2,27, 19,6	28,19, 32,22	19,32, 35		18,19, 28,1	15,19, 18,22	18,19, 28,15	5, 8, 13,30	10,15, 35	10,20, 35,26	19,6, 18,26
3	Length of moving object	8,35, 29,34	19		10,15, 19	32	8,35, 24		1,35	7, 2, 35,39	4,29, 23,10	1, 24	15, 2, 29	29, 35
4	Length of non-moving object	15,14, 28,26		1,40, 35	3,35, 38,18	3,25			12,8	6,28	10,28, 24,35	24,26	30,29, 14	
5	Area of moving object	3,15, 40,14	6,3		2,15, 16	15,32, 19,13	19,32		19,10, 32,18	15,17, 30,26	10,35, 2,39	30,26	26, 4	29,30, 6,13
6	Area of non-moving object	40		2,10, 19,30	35,39, 38				17,32	17,7, 30	10,14, 18,39	30,16	10,35, 2, 18, 40,4	
7	Volume of moving object	9,14, 15,7	6,35, 4		34,39, 10,18	2,13, 10	35		35,6, 13,18	7,15, 13,16	36,39, 34,10	2, 22	2, 6, 34,10	29,30, 7
8	Volume of non-moving object	9,14, 17,15		35,34, 38	35, 6, 4				30,6		10,39, 35,34		35,16, 32,18	35, 3
9	Speed	8,3, 26,14	3,19, 35,5		28,30, 36,2	10,13, 19	8,15, 35,38		19,35, 38,2	14,20, 19,35	10,13, 28,38	13, 26		18,19, 29,38
10	Force	35,10, 14,27	19,2		35,10, 21		19,17, 10	1,16, 36,37	19,35, 18,37	14,15	8,35, 40,5		10,37, 36	14,29, 18,36
11	Tension, pressure	9,18, 3,40	19,3, 27		35,39, 19,2		14,24, 10,37		10,35, 14	2,36, 25	10,36, 3,37		37,36, 4	10,14, 36
12	Shape	30,14, 10,40	14,26, 9,25		22,14, 19,32	13,15, 32	2,6, 34,14		4, 6, 2	14	35,29, 3, 5		14,10, 34,17	36, 22
13	Stability of object	17,9, 15	13,27, 10,35	39,3, 35,23	35,1, 32	32,3, 27,15	13,19	27,4, 29,18	32,35, 27,31	14,2, 39,6	2, 14, 30,40		35,27	15,32, 35
14	Strength		27,3, 26		30,10, 40	35,19	19,35, 10	35	10,26, 35,28	35	35,28, 31,40		29,3, 28,10	29,10, 27
15	Durability of moving object	27,3, 10			19,35, 4,35	2,19, 4,35	28,6, 35,18		19,10, 35,38		28,27, 3,18	10	20,10, 28,18	3, 35, 10,40
16	Durability of non-moving object				19,18, 36,40				16		27,16, 18,38	10	28,20, 10,16	3, 35, 31
17	Temperature	10,30, 22,40	19,13, 39	19,18, 36,40		32,30, 21,16	19,15, 3,17		2,14, 17,25	21,17, 35,38	21,36, 29,31		35,28, 21,18	3, 17, 30,39
18	Brightness	35,19	2, 19, 6		32,35, 19		32,1, 19	32,35, 1,15	32	19,16, 1, 6	13, 1	1, 6	19, 1, 26,17	1, 19
19	Energy spent by moving object	5,19, 9,35	28,35, 6,18		19,24, 3,14	2,15, 19			6,19, 37,18	12,22, 15,24	35,24, 18,5		35,38, 19,18	34,23, 16,18
20	Energy spent by non-moving object	35				19,2, 35,32					28,27, 18,31			3, 35, 31

Figure 2.2: TRIZ contradiction matrix [Altshuller et al., 1998]

The idea behind the implementation of the TRIZ methodology, guided by the ARIZ

procedure, is that through the application of one or more of the 40 inventive principles and the 76 standard solutions available, the designer is capable of consolidating a feasible technical solution, which solves the design contradiction initially identified.

However, an important limitation related to the implementation of this tool is that it requires the conception of the technical problem in terms of a functional contradiction, which is not always easily identifiable during conceptualization stages, particularly when the product definition is not yet concrete.

**Innovation Workbench** The structure and strategic approach of TRIZ has served as a basis for the development of a number of tools that intend to provide a practical model for the application of TRIZ's principles. Such is the case of Innovation Workbench [Zlotin and Zusman, 2005], a software that seeks to automate Altshuller method and exemplify the solution strategies. However, it is a fixed platform that cannot be nurtured by new knowledge.

#### 2.2.2.4 Polovinkin's rules and subsequent works

Subsequent developments have been built upon the work of TRIZ, such as Polovinkin's heuristics [Polovinkin, 1991] and the work of Tessari and De Carvalho [Tessari and De Carvalho, 2007] [De Carvalho et al., 2004]. Fundamentally, these approaches aim to continue nurturing the extensive knowledge base of TRIZ, as well as explore new possible heuristic rules.

**Polovinkin's heuristics:** Polovinkin, on one hand, proposes a set of 12 categories of heuristics, containing around 200 rules in total. The categories include, among others: Shape transformations, structure transformations, transformations in space, transformations in time, transformations of movements and forces, transformations of materials, expedients of differentiation and quantitative transformations.

Being born within the same context of TRIZ, Polovinkin's work is much less widespread. This is due to the fact that its knowledge base was constructed during the period of the USSR and therefore limited to the consultation of expert works, namely patents, within this context, and has remained without application by Western practitioners given that for the most part it remains in Russian, its original language.

The nine groups of Polovinkin's rules are:

- Transformation of shape
- Transformation of materials
- Transformation of structures
- Differential resources
- Transformation in space
- Quantitative modifications
- Transformation in time
- Transformations related to evolutionary trends
- Transformation of movements and mechanical actions

Polovinkin's rules have the advantage that they can be implemented without a defined methodological framework. Their application enables the covering of a broad spectrum within the space of possible solutions because of the generic and universal character of the rules. However, there is no formalization of the design problem to solve, which can consequently derive in a somewhat ineffective application of the rules.

**De Carvalho's 121H:** De Carvalho's contribution is based on the proposition of a simplification of the work of Polovinkin, based on the assumption that some of the rules proposed by his work are strictly delimited by technical and legal condition of the context in which they were created, namely, the USSR in 1985.

Therefore, the original 200 rules are reduced to a total of 121, categorized in 9 groups. In order to broaden the scope of the heuristics proposed by Polovinkin, the 121H count with patent examples from different backgrounds, no longer limited to the context of the USSR.

#### 2.2.2.5 MAL'IN and Heuristics tree

Some developments have been oriented towards other stages of the design process, different from initial ideation. Such is the case of the work proposed by Nadeau, whose work is focused in the stage of functional structuring of the product, paying special attention to the generation of architectural alternatives. His method approaches the design process from the functional decomposition of a system, and the subsequent creation of relationships between the detected functions, based upon level and function similarities within the system.

This methodology emerges as an attempt to simplify the work of Altshuller, by attacking the main difficulties of this approach, namely, the resolution of technical contradictions.

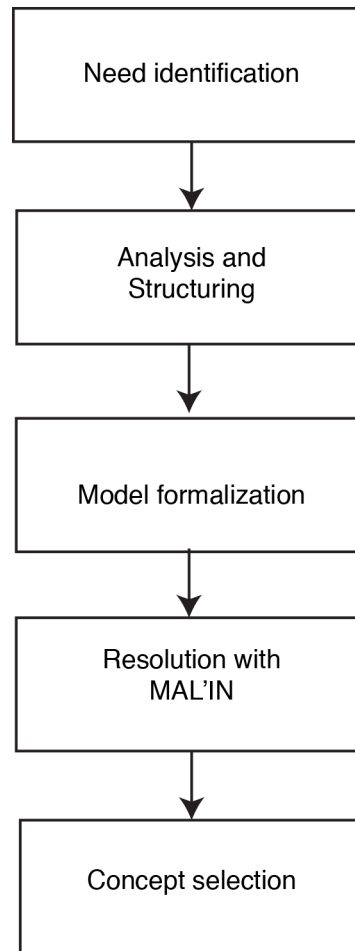


Figure 2.3: Nadeau: MAL'IN approach

For this purpose, the authors set a methodological approach (See Figure 2.3), as well as a number of strategies to eliminate the technical contradictions:

- **Separate in time:** Taking advantage of the different states, values or conditions of a single requirement throughout the system's life cycle, one can make present a particular characteristic of the system when needed, and make it absent when not required.
- **Separate in space:** Create a physical separation between conflicting requirements that occur simultaneously, so that the required condition is present where needed, and absent or inverse elsewhere.
- **Separate among parts:** When a condition is needed at a local scale, but conflicts at a global scale, the separation among parts solves the contradiction.

- **Separate by conditions:** If a given resource demands two different and conflicting values in a single stage of the system's life cycle, the separation by conditions will make the conflicting resources available at a local level and not elsewhere.

Other developments related to Nadeau's research are applied to specific industries such as aeronautics, where the heuristic rules have been put to the service of design processes oriented towards the prevention of failure in high-complexity mechanical components. Additionally, some work has been devoted to the analysis of design situations within specific organizations. In this case, the authors propose, in a first instance, a set of 4 heuristics applicable throughout the project, with the purpose of simplifying the product from the number of components and the interactions between them. The result of this work is the analysis and characterization of knowledge within said context, which adds a meaningful value to the resulting heuristics, contextually speaking.

#### 2.2.2.6 AULIVE

A particularly interesting approach towards the integration of heuristics throughout the design process is the one proposed by AULIVE [Aulive, 2014].

AULIVE is an on-line platform that intends to trigger innovation processes through several tools such as patent analysis and functional principles exploration.

The following is the method behind the development of AULIVE's tools:

- **Aim:** Determine the particular value and functions of the product to be developed. These values and functions are determined under the perspective of four elements: Performance, harmful effects, user ease and expense.
- **Use:** Analyze the usage situations of the product in time and space.
- **Link:** Using tools as patent analysis, decompose the product concept into functions that can be identifiable in existing solutions, in order to determine common properties and functions of similar products or applications in different domains.
- **Import:** Use references of functions and properties of similar products and applications in other domains as an inspiration for new developments

- **Vary:** Change the values, properties and functions of a product in order to create new alternatives
- **Elect:** Choose a particular design direction based on the innovative level detected on the concept.

## 2.3 Observations on Literature Review

With regard to design heuristics, as it can be seen, although previous studies have been carried out in the field of heuristics, its specific approximation to the field of design is a field under development. The works cited above have made a significant contribution to the field, but the current works propose, in general, merely a number of separate tools. Therefore, a full methodological integration to the design process is yet to be explored.

Additionally, very little research has been made regarding the value of the expertise of experienced design practitioners and especially its impact in the applications of design methodologies. In this sense, there is a wide opportunity towards the implementation of a method that incorporates, generalizes and enables a useful recovery of previous experiences as input for the design process.

On the other hand, aspects related to the social, geographical and cultural conditions might have a significant impact in the way design processes are executed in the local context, and this is a point worth noting for future developments.



## Chapter 3

# Knowledge categorization and retrieval through heuristics

From the literature review it is possible to note the relevance of understanding the heuristic nature of design processes. We have also seen that the basis of heuristic approaches is the existing knowledge within organizations. Furthermore, we have seen how heuristic-based approaches can serve in the problem-solving activities placed within a design context

Therefore, in order to further comprehend the usefulness and applicability of heuristics in design environments, it becomes necessary to explore two important aspects of creative processes:

- At what stages of the design process is it relevant to count on existing knowledge as a resource for decision making?
- What means can be used to capture and reuse this knowledge in creative processes in an effective manner?

These questions will be addressed in the following sections.

### 3.1 Integration of heuristics in the design process

In principle, the concept of heuristics itself, understood as knowledge that exists from previous experiences and can be readily available for extrapolation in new design situations,



indicates that such concept can be implemented whenever a design team faces a problem-solving situation, in which knowledge derived from past experience can be of use to come up with interesting solutions.

In particular, the stages of the design process that demand the creation, detailing or re-design of technical concepts can obtain special benefits from the implementation of heuristics, because this is generally where new solutions to design problems emerge.

However, an important matter arises at this point: Given that there is a numerous amount of design methodologies available, how to specifically determine where and how to use heuristics?

In order to solve this question, the present research has explored some of the most relevant approaches in design methodologies with the purpose of pointing out specifically how to integrate the implementation of design heuristics with structured design practices.

An overview of said exploration is presented in Table 3.1

Table 3.1: Use of heuristics in design processes

METHODOLOGY	STAGES								
Ulrich & Eppinger	Planning	Concept development		System level design		Detail design	Testing and Refinement		Production Ramp-up
Pahl & Beitz	Planning and clarifying	Conceptual design		Embodiment design	Detail design				
Tidd & Bessant	Idea generation			Research, design and development			Prototype production		Manufacturing and sales
Roozenburg & Eekels	Analysis	Synthesis					Simulation	Evaluation	Decision

In Ulrich and Eppinger [Ulrich, 2003], for instance, the method proposed by the authors offers two possible areas of intervention for design heuristics: Concept development and System Level Design. The activity of concept development is, in this case, a process of its own, that starts with the identification of customer needs and continues with the definition of product specifications. At this point, the design engineer has enough information about a given design problem to begin developing product concepts. Ulrich's methodology proposes a set of tools to approach the generative stage, such as the combination table and the clas-

sification tree. The aim of these tools is to diversify the sources of inspiration and propose a wide spectrum of configuration alternatives for concept development. Thus, the utilization of heuristics can be handy in this stage of the process. The integration can be achieved by determining particular product specifications that represent challenges in product development. In this case, heuristics can be used as a generative technique, without an in-depth functional exploration of the system.

The stage of System Level Design demands the decomposition of the elaborated concepts into subsystems and components towards the definition of a product architecture, much like the Technical Organization Chart proposed in the present methodology, which will be described in Chapter 4. In this sense, the design engineer can use heuristics to clarify and transform the interactions between the identified components and subsystems.

The methodology proposed by Pahl & Beitz considers the functional disaggregation of a system in the concept development stage [Pahl et al., 2007], putting special emphasis on the representation of the interactions between subsystems, through the characterization of functional flows. Hence, it is possible to connect the usage of heuristics during this stage by interpreting the relationships between elements from a cause-effect perspective, which is a crucial point in the implementation of heuristics in design, as it will be further described in the next chapter

A particularly interesting characteristic of the connection between Pahl's methodology and Heuristics is that said method demands a level of abstraction of the product concept that generalizes it in a sense, making it easier to associate ideas from different domains to the solution principles that are sought during this stage.

In the embodiment design stage, on the other hand, the methodology focuses on the actual characterization and disposition of components in the final design with the goal of achieving functional efficiency. Here, heuristics can help sort out the difficulties in distributing or defining the final shape of particular elements.

Tidd and Bessant's model is specifically oriented towards the incorporation of innovation in the design practice and what is known as New Product Development (NPD). [Tidd et al., 2001].

This process, however, is not specific in tools and strategies to be followed in each of the stages, and has a rather general approach to the definition of the stages. In particular,

the process proposed by the authors involves an idea generation stage and a research, design and development process. Both of them can theoretically take advantage of the utilization of heuristics. Particularly, the method can derive special benefit from heuristic rules because understanding and evaluating concepts from diverse domains can give a perspective of market needs and expectations, which is a strong driver of this methodology. In this sense, a heuristic-based approach can be connected as a support tool for the specification of both stages, and the process can either be followed in technical detail or merely as a generative technique.

Roozenburg and Eekels' basic design cycle outlines general stages that design engineers often follow when working on a design task [Roozenburg and Eekels, 1995]. In this sense, the process is linked to several strategies that can be implemented in each of the stages, but does not provide a specific methodical approach. Interestingly, in this methodology the synthesis stage in particular deals with the "combining of separate things, ideas, into a complete whole" [Boeijen and Daalhuizen, 2010], which results in a tangible product concept. The process to reach said concept is, however, vaguely defined. Heuristics can provide a structured approach towards the obtaining of said concept, by offering a pathway of activities and support tools that guide the design engineer in this creative process.

## **3.2 Knowledge categorization**

Having seen the applicability of heuristic approaches in the design process, the next step towards the integration of heuristics in the design process is to count with a tangible manner in which this knowledge can be accessible for organizations and companies, avoiding the often general practice of approaching problems based only upon experience and know-how of designers, or arbitrary choices derived from strong personalities within a company, or the history of the company itself.

But, how to do so? How to provide a certain structure to said existing knowledge?

In general, it is possible to develop what is known as "heuristic rules" from the existence of a knowledge base that has been previously collected and categorized. These rules, derived from and built upon the interpretation of different relevant sources, can be created upon the determination of patterns that can be later structured in the shape of general problem solving strategies, which in turn can be transformed into specific design solutions.

The mentioned rules must have a global character, meaning a large spectrum of applica-

tion. What gives them a heuristic profile is that they might have not been proved (or can not be proven) but their justification leaves no place for doubt. In general, a heuristic is simple, explicit, practical and easily implementable. Heuristics must be, in a sense, "universal", and it should be possible to interpret them within different contexts of design. Heuristics represent the translation of an experience, the formalization of the state of the art of the engineer, and the analysis of existing solutions.

As a source for the present study, the work performed by Nadeau et. al for Turbomeca has been taken as a reference [Pailhès et al., 2007]. The author proposes a set of 78 heuristic rules, which are the result of an extensive analysis of the available resources related to problem solving strategies, such as those proposed by Altshuller and Polovinkin, and have been optimized and structured in a way that enables the designer to quickly interpret the knowledge and functional principles behind them and put it to use in any design situation.

In consequence, this work serves as a starting point for analysing the impact of incorporating heuristic approaches into design processes, not only because it gives the possibility of already counting with a knowledge structure provided by the authors, but because it considers relevant works in the field for the formulation of said rules.

Particularly, the heuristic rules provided by Nadeau are based upon the concept that there is a frequency of utilization of the laws of evolution in systems, and that a particular structure can be created with the goal of providing an organized approach to the implementation of said laws.

In order to provide a method for the incorporation of Nadeau's rules into design practices, first it is important to understand how the knowledge base proposed in his work has been created. This will be detailed in the following subsections.

### 3.3 Structuring and use of the heuristic tree

The detailed composition of the 78 heuristics that serve as a basis for the present work has been developed and discussed in the thesis presented by Morillon [Morillon, 2009], which is based upon Polovinkin's rules, the laws of evolution, the standard solutions, the innovation principles as defined by the theoretical principles of TRIZ, and general engineering knowledge.

These heuristic rules are built up into a hierarchic tree-like structure (See Figure 3.1. Fragments of sentences, which level of abstraction decreases along the course of the branches,

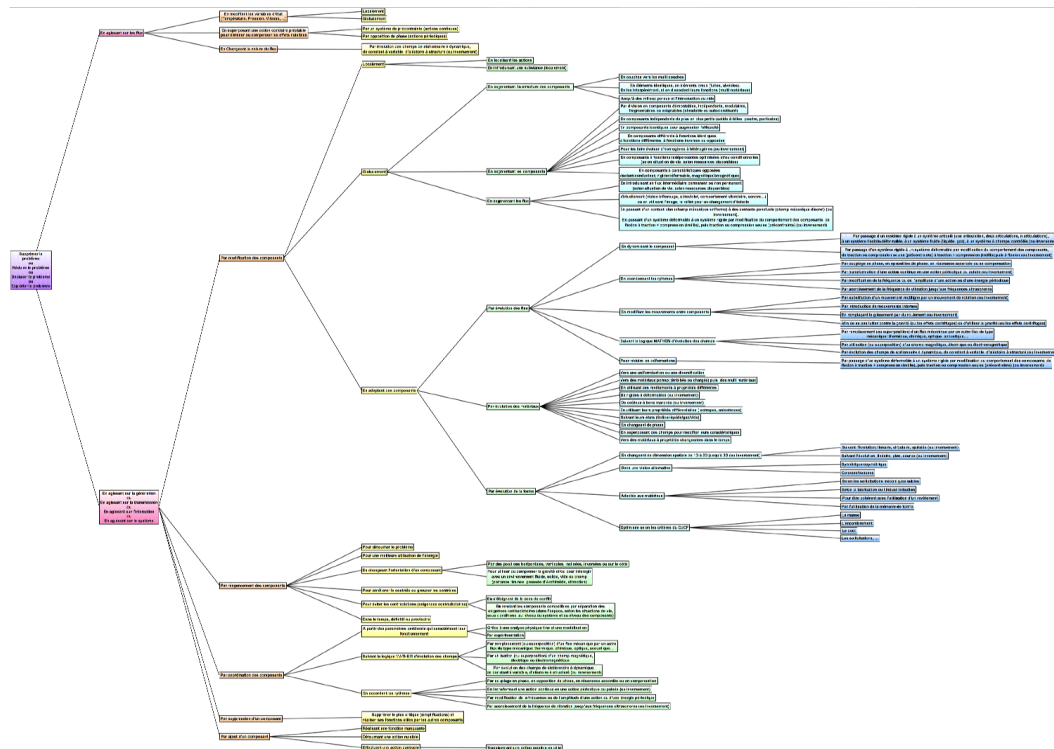


Figure 3.1: Heuristic tree [Pailhès et al., 2007]

configure the structure of 78 rules.

The branched structure also offers the possibility for an initial portion of a rule to unfold into several different strategies, thus enabling the designer to explore diverse possible solution principles for a single problem

Each rule is conformed by segments of sentences that grow in level of detail as they escalate throughout the structure of branches. The level of detail corresponds to a hierarchical organization that helps designers to identify the kind of approach they want to take on a problem, and determine the sort of solution strategy they wish to implement.

The starting point for the utilization of the tree is the identification of a particular design problem. Once it has been identified, the designer can proceed to use the systematic method proposed here, which is composed of different stages.

This structured procedure enables the designer to approach the problem, leading down to increasingly precise levels. Thus, the designer will be able to choose a branch of heuristics which will lead to an explicit statement that can be later interpreted in context in order to generate solutions.

The following subsections describe the systematic approach for the utilization of the tree.

### 3.3.1 Systematic analysis of the possibilities of resolution

The first question that the heuristic tree challenges designers to solve is what kind of specific action is expected to be performed on the problem that has been previously identified.

At this point, there are four possible actions to be taken:

- Suppress or eliminate the problem
- Reduce the problem
- Displace the problem
- Exploit the problem

The selection of a particular action depends largely on the possibilities and resource availability of each design situation. At first sight, it might always be preferred to fully eliminate the design problem, but guiding the designer towards thinking of different resolution alternatives that do not fully suppress the problem might be, in some cases, more resource effective and equally satisfying of the design requirements.

Once the first decision is made, the team can move on to the next stage.

### 3.3.2 Systematic analysis of the area of action

The second step involves the selection of the area of action in the system. This selection is intrinsically bound to the Cause-Effect model, detailed in Chapter 4. There are five possibilities of action:

- Generation
- Flow
- Transmission
- System
- Interaction

At this point, it is also suggested to evaluate all the available resources for the particular situation at hand. A full overview of the possible resources will be given in the description of the methodological approach.

### 3.3.3 Systematic analysis of the ways to act upon the problem

The first-level choice is focused on determining the kind of action to execute on the system.

The actions focused on altering the generation, transmission, interaction or the system act on the components, therefore a number of alternatives of heuristic rules related to the transformation of components are proposed (See Figure 3.2).

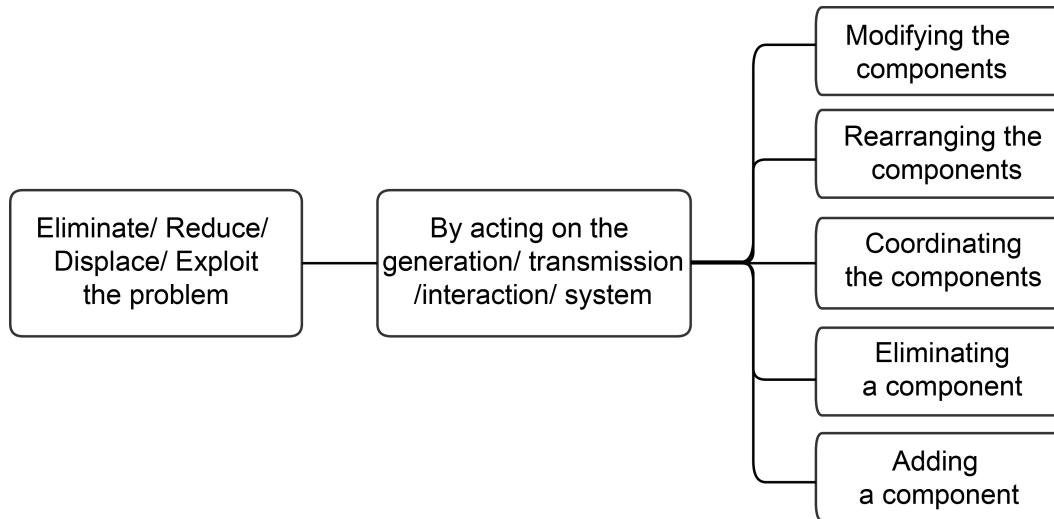


Figure 3.2: Actions on the generation, transmission, interaction or the system

The other possibility is to act on the flow or flows that transit within the selected system; by acting upon them the designer is indirectly counteracting the potential negative effects that are affecting the system.

In this sense, it is possible to either change the nature of the flow or to act on said flow without changing its nature by modifying the state variables or by superposing a previous action in order to eliminate or compensate the undesired effects. (See Figure 3.3)

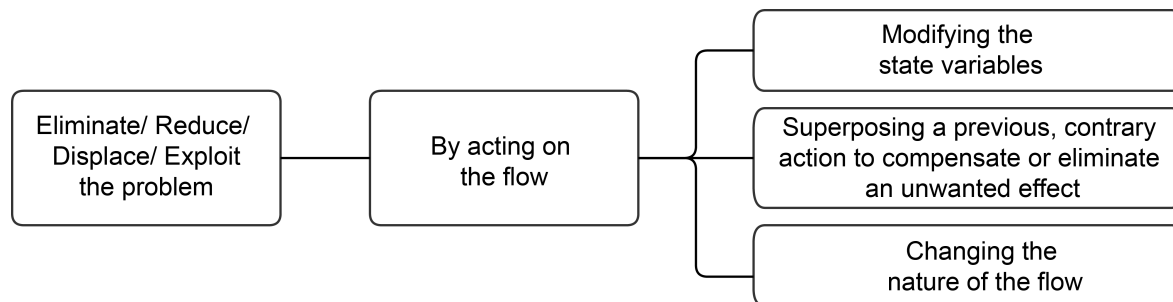


Figure 3.3: Actions on the flow

The utilization of heuristics is then performed by choosing a route from the possible alternatives that emerge. Afterwards, by following the selected level of resolution within the spectrum of the heuristics tree, it is possible to escalate in an increasingly precise manner through the diverse levels of the heuristic tree structure. (See Figure 3.4)

Depending on the objective of the design activity and the dynamism of the group involved in the implementation of the heuristics, the last levels of the structure can be useful or not. Thus, having identified the particular situation of the design activity being developed, it is possible to evaluate the different levels of the heuristic tree, and therefore build up a specific expression that describes a punctual, increasingly specific approach to attack the design problem.

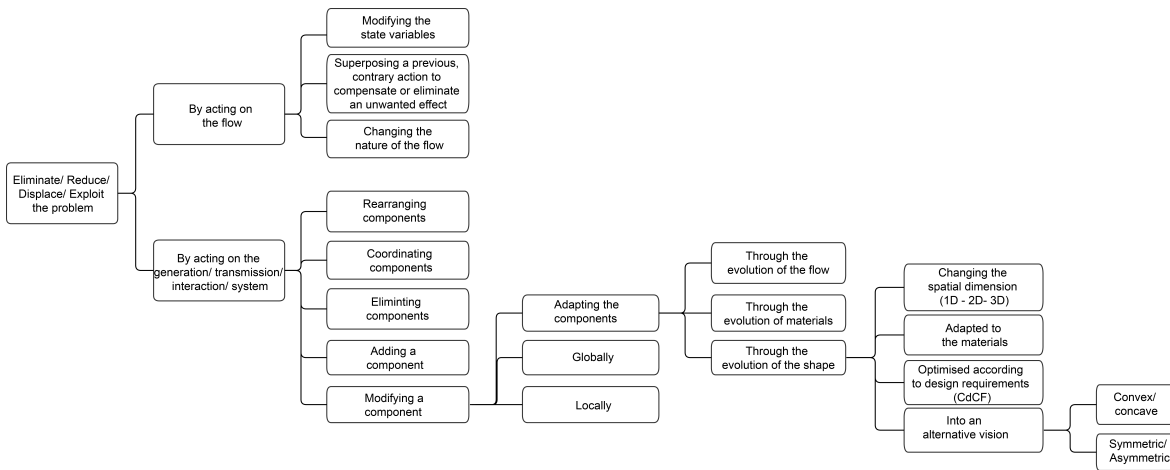


Figure 3.4: Representation of a branch of heuristic rules

The different branches of the heuristics tree have been evaluated with the aid of diverse examples [Morillon, 2009]. These examples have been derived from the analysis of patents and the study of an existing system, in this particular case, a ring support for high pressure turbines, performed for the company Turboméca (Safran Group).

For confidentiality reasons, it is not possible to give detail regarding the evaluation of the heuristics. However, the conclusions of this study show that the different heuristics that have been constructed are coherent with the evolution of techniques and technologies used in the industrial sector of turbomachinery.

A redundancy of the heuristics has also appeared during this study, meaning that many similar solutions have appeared through different paths. However, this is not a problem. On



the contrary, it is an indication of the robustness of the method and different users might find the same solutions while following different thought processes.

As a result of Morillon's study, it is possible to say that this approach enables designers to have an exhaustive view of the different possible attack angles for a given design problem. Furthermore, the approach makes it possible to classify the existing solutions of the market and perceive the directions from which a radical innovation might come.

### **3.4 Knowledge retrieval**

From what we have seen so far, it is evident that with a heuristic approach it is possible to quickly propose guidelines for reflection to the group of designers or engineers involved in the development of a solution. As a matter of fact, due to the systematic nature of the approach, one of its key advantages is that the functional principles explored in the heuristic tree can be of use for a vast range of design issues.

However, once a particular branch of the tree has been selected, the task at hand for the designer is consequently to interpret the defined heuristic within their context of implementation, with the purpose of arriving to the generation of actual design solutions. In Nadeau's line of work, this process was sorted out with the provision of exemplifying cards that contained applications of the different heuristic principles. The applications, however, were limited to the field of turbomechanics and aeronautics, restricting the possibilities of extrapolating the principles to other areas of knowledge, and potentially losing the key advantage of the generality of the approach.

Therefore, one of the main contributions of this research is to support the heuristic approach with the development of a tool that consolidates both the heuristic rules and application examples from different fields (e.g., engineering, industrial design and biomimicry). The purpose of this consolidation is not only to facilitate the comprehension of the functional principle behind each of the rules contained in the tree, but to compile a knowledge base related to each of the strategies in a manner that can be accessed on demand. The goal is to help designers understand how the different solution principles can be integrated into their creative process, and provide a resource to which they can resort when inspiration for the resolution of design problems is needed.

The support tool developed to enable the retrieval of knowledge associated with each

heuristic strategy is an online-based software development that incorporates and enriches the work done by Nadeau in the Heuristics Tree.

Broadly, the interaction of the designer with the software will guide the user through a set of choices akin to those presented in the construction of the tree, starting from the kind of action to be taken –elimination, displacement, reduction, etc.– and the specific location of the redesign action –generation, interaction, transmission, etc.–, concluding with the selection of a particular solution principle.

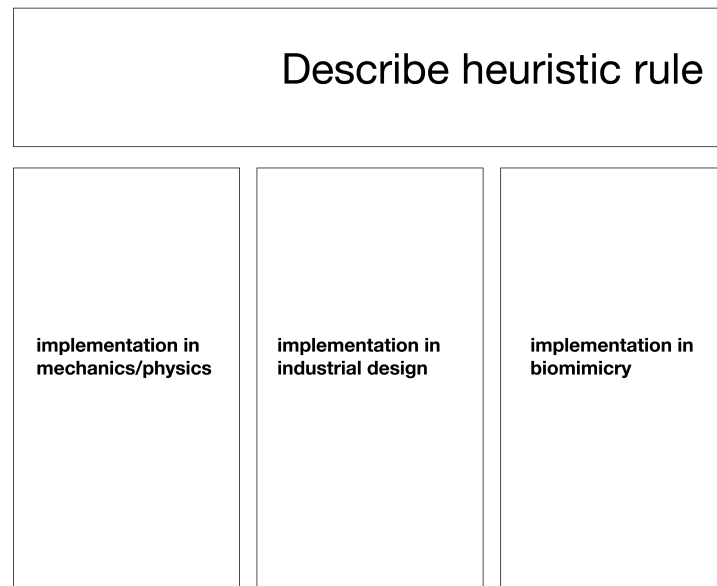


Figure 3.5: Heuristic Card diagram

At the end of the decision-making process, the designer will encounter not only the summary of the heuristic branch selected in the shape of a strategy, but also a compilation of examples that display application of the functional principle under question in diverse areas:

- An example of an industrial application
- An example of a consumer product
- An example derived from the natural world

The general outlining of the cards can be seen in Figure 3.5

Each of the examples is accompanied of details on how the principle works in each of the cases (See Figure 3.6). Additionally, the physical or mechanical basis of the functional

principle is also shown, as further guidance for the detailing of functional aspects of the design.

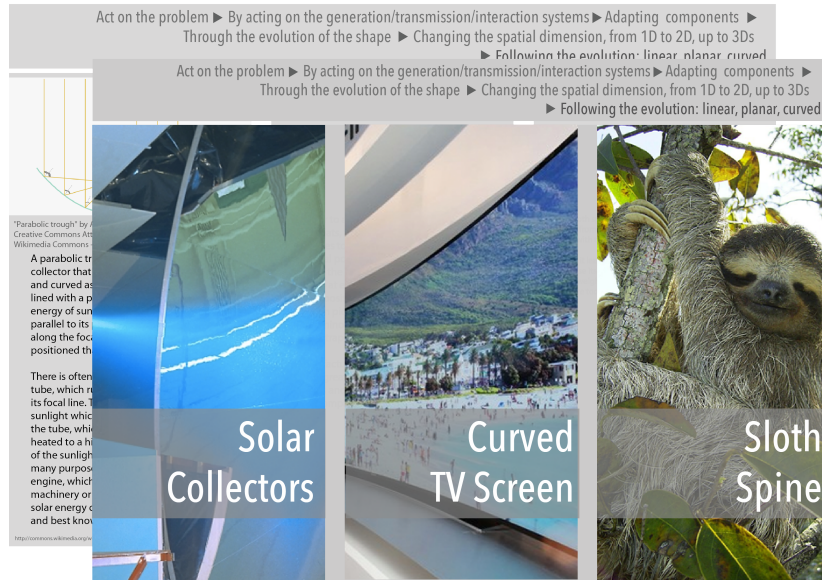


Figure 3.6: Heuristic Card example

The ultimate goal is to trigger creative thinking in the designer or design team that implements the present methodological approach, by providing them with tools to explore an ensemble of solution strategies applicable to a wide range of design problems.

Further detailing of this support tool specifically and the background knowledge related to heuristics presented in this Chapter, will be given in Section 4.1.3.1, where it will be placed in context with the rest of the method proposed in this research.

In the next chapter, a clear overview of the integration of heuristics within the design process, and the support tool mentioned above, is outlined and detailed.

## Chapter 4

# Heuristics-based method development and implementation

In the previous chapter we have seen the possibility of implementing heuristic-based tools for the resolution of design problems.

Nadeau's Heuristic Tree and the Heuristic Cards developed in the present study can be employed as stand-alone resources when an engineer has enough clarity on how to analyze, interpret and extrapolate the contents of said tools.

However, this is not always the case. In order to solve this gap, the research provides a structured problem solving approach that helps designers to nail down design tasks more effectively, by resorting to existing knowledge in a structured manner (in this case, the Heuristic tree and the cards).

The purpose of establishing said approach is helping maintain the generality of the tools by providing specific sets of steps and tools to make effective use of the existing resources.

Furthermore, by creating a structure approach for the incorporation of the cards and the heuristic rules, it is possible to create as well an approach for the capitalization of emerging knowledge within organizations, with the purpose of contributing to the consolidation of said knowledge derived from design processes, and making it available for future situations.

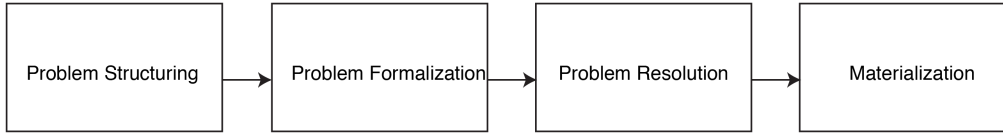


Figure 4.1: Use of heuristic rules: Method

## 4.1 Use of heuristic rules

The proposed procedure for the introduction of heuristic rules and their associated cards in the design process comprises three successive stages: Problem structuring, Problem formalization and Problem resolution (See Figure 4.1).

The process encompasses as well the definition of a set of particular tools that can be used in each of the stages to further clarify the design task at hand, and consequently make a more efficient use of the heuristic rules in the design process.

Each of the stages and their respective tools will be described in the following subsections.

### 4.1.1 Problem Structuring

The first step towards the resolution of the design problem requires the designer to fully understand the nature of the problem itself. For this purpose, the first requirement is the development of a functional decomposition of the overall system into the specific functional blocks and flows that characterize the product under question. This will enable the designer to have a visual representation of the design situation.

For the functional disaggregation process, we propose the utilization of a set of tools derived from the APTE approach, that can bring a clearer understanding of the system. (See Figure 4.2) A brief description of each of the tools will be given below.

The first of the tools is the Functional Analysis [de la Bretesche, 2000], as explained by Figure 4.3. This method will enable the designer to understand which is the main function of the product under question, and which elements (both internal and external) surround –and impose restrictions on– said function.

Then we recommend to perform a Converter-Transmitter-Actuator (CTA) analysis [Sallaou, 2008], which will enable the designer to understand how the main flow of a product travels within

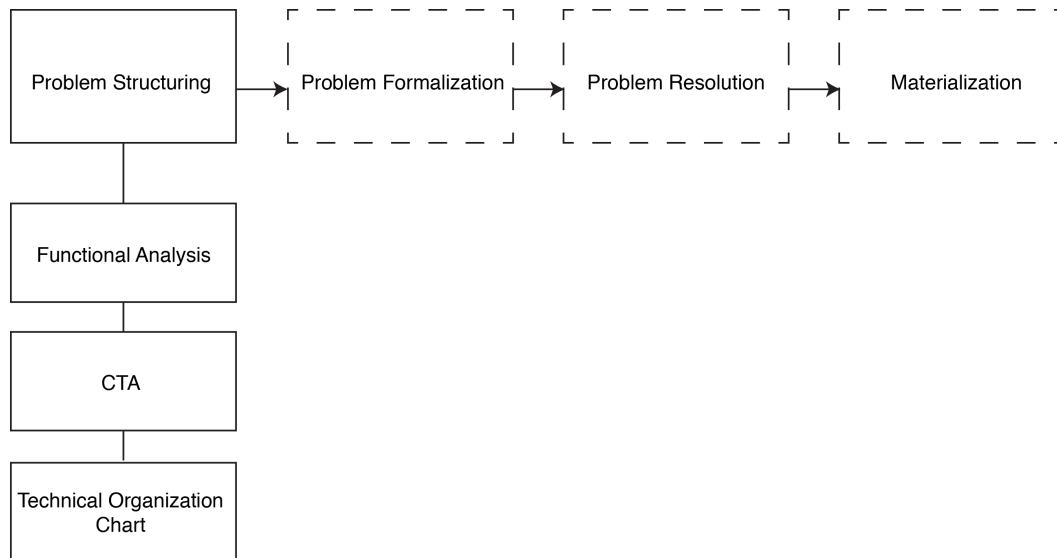


Figure 4.2: Problem Structuring

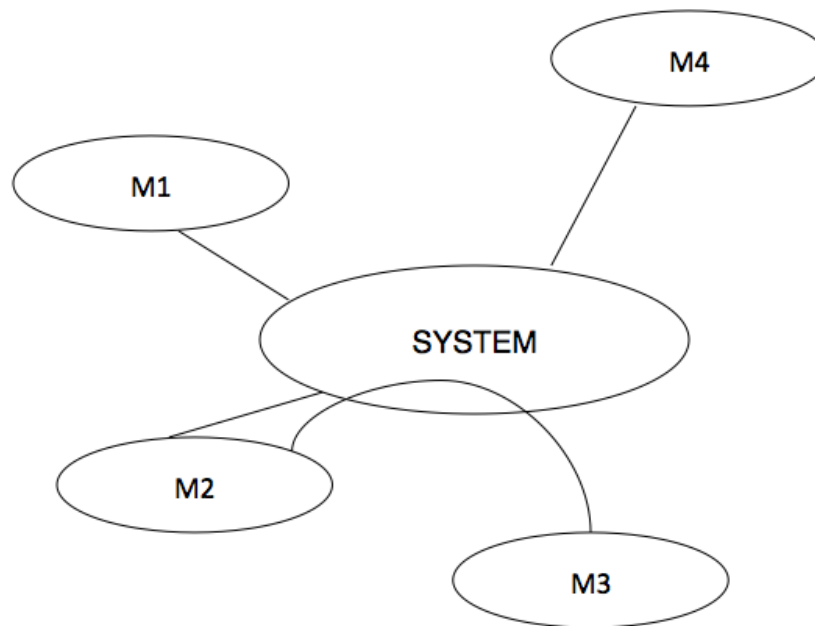


Figure 4.3: Functional Analysis

the system, and how it connects the key components. (See Figure 4.4)

The final tool for this stage of the process is the Technical Organization Chart [Sallaou, 2008].

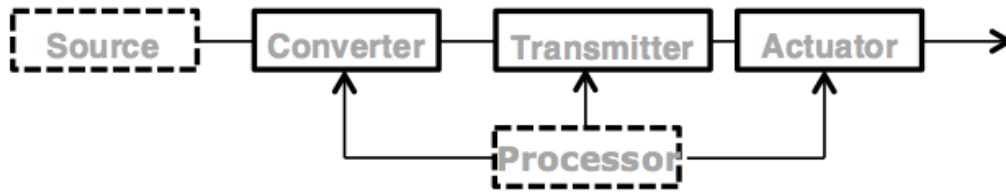


Figure 4.4: Technical Organization Chart

(See Figure 4.5). In order to develop the tool, the designer must describe the product at three main levels [Pailhès et al., 2011]:

- Products and components.
- External environments.
- Interactions within the product and with external factors that incise in the product.

Once these elements have been identified, the components must be hierarchized.

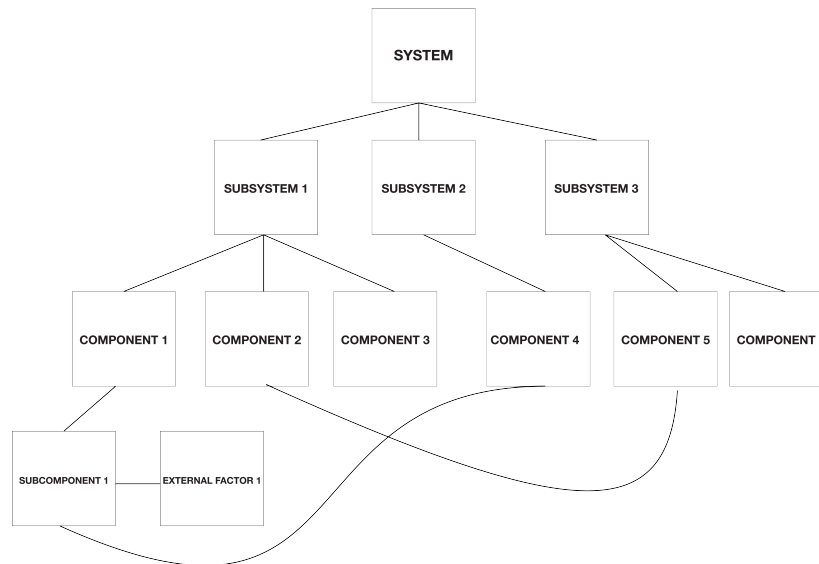


Figure 4.5: Technical Organization Chart

Afterwards, the designer can determine the conflicting components, and select the level at which the problem will be attacked, starting from the global system and descending to

component or sub-component levels. At this point, the next step is the determination of functional blocks, which involves zooming into the selected level and describing the interactions within a subsystem.

The determination of functional flows is of crucial importance for the subsequent work. The diagram will help classify the flows according to their characteristics (e.g., matter, energy or signals) and identify their provenance.

At this point, it is important to establish that an accurate configuration of a Technical Organization Chart, as such, depends largely on the expertise and ability of the designer or design team. In this sense, it is often easy to spot where the system presents the most significant problems, and therefore where to focus the redesign efforts. But at the same time, the lack of experience or practice in the development of this particular tool can lead the designer to obviate or miss connections or disaggregation possibilities within the system. This would eventually mean that one could miss a few problematic elements of the system, or the points where the redesign could have the most meaningful impact.

Therefore, when the problems do not show up immediately, it can be helpful to count with a methodological aid for designers to envision the actual possibilities of configurations and interactions between subsystems and components.

For this purpose, the research has formalized an approach that helps designers to quantify all the possible interactions within a system, in order to provide the designer a tool for the proper identification of the interactions that can pose problems in the product. The approach operates as follows:

Consider a generic Technical Organization Chart. If we consider all the possible interactions between components, there will be a  $k$  number of combinations of elements selected from a domain of  $n$  elements. This means that  $k \geq 2$  and  $k \leq n$ . Given that in this particular case it is of interest of the designer to understand the interaction between two components, regardless of the level at which the elements are located in the systemic structure,  $k = 2$ . Having a finite set of elements  $E$ , the set of combinations of  $k$  elements is noted by  $C_k^n$  and it can be calculated with the following equation:

$$C_k^n = \frac{A_k^n}{k!} = \frac{n!}{k!(n-k)!} \quad (4.1)$$

where  $\frac{A_k^n}{k!}$  is the number of  $k$  possible arrangements of  $E$ .



At this point, however, the actual number of interactions remains uncertain, given that the amount of flows that connect two particular subsystem has not yet been determined.

In this sense, we can determine every possibility of interaction as  $I_{k_j}$ , granted that the interaction between components  $s_k$  and  $s_j$  exists.  $I_{k_j}$  represents, therefore, the set of flows that connect both components, independently of their nature.

No further detailing of the flows is required at this point, however, given that this subject will be tackled in the following step of the methodology.

This mathematical approach will, in the end, deliver a number of all the possible combinations between two elements, these being components, systems or external factors.

Having established all the possible interactions among components, what follows is the determination of the specific interactions that pose significant problems in a particular system. For this purpose, an evaluation process must be carried out, scoring the relevant interactions and determining which has the largest impact and consequently demands a redesign action. At this point, the evaluation does not fully detail the functional characteristics of the interaction, but rather qualifies the visible effects of it.

For the scoring process we provide an evaluation scale based upon the identification of a number of relevant aspects that will serve designers to decide where to focus the redesign efforts. These elements are:

- A classification of the generated effects between two elements, based upon the tool MAL'IN [TREFLE, 2003].
- An evaluation of the costs associated with taking action over the identified problems.
- An analysis of the level at which the redesign action takes place within the Technical Organization Chart

#### 4.1.1.1 Evaluation of interaction effects:

The scale proposed in Table 4.1 gives the lower value to the interactions that do not affect negatively the system's behaviour, and an increasingly higher value to the interactions which generate the most negative impact in the system.

Of course, it is clear that not all the combinations obtained from the previous operation are meaningful, in the sense that there might be no actual interaction between a set of particular

Table 4.1: Interaction rating

Criteria	Weight	Scale	Value
Interaction Effects	w1	No effect/ Positive effect produced	0
		Positive effect insufficient	1
		Positive effect not produced	2
		Undesired effect produced	3
Cost of Intervention	w2	No cost	0
		Low cost	1
		Mid cost	2
		High cost	3
Location Level	w3	Subcomponent	0
		Component	1
		Subsystem	2
		System	3

elements. In such case, reasonably, the value is 0. In other cases, the interaction between components produces effects that are intended or desired; in other words, these interactions occur according to the design specifications. In this case, since the interaction between both components causes no detriment to the system, the value is also 0.

In cases where the intended or desired effect of an interaction actually occurs, but does not fulfil the requirements originally set by the design specs, the interaction is rated with a value of 1.

In cases where a desired effect does not occur at all, meaning that the components' interaction does not produce the action that was expected by design, the score of the interaction is 2.

And finally, when an effect that has not been foreseen and was not intended in the design appears, causing damage or unwanted impacts in the product, the interaction between these components is rated with a value of 3.

#### 4.1.1.2 Evaluation of cost of intervention:

The rating of this particular item depends largely on the resources available within the organizations, and the ranges or values assigned to every metric in the scale have to be selected by the team. In this sense, it is obvious to assume that those changes or redesign actions that demand less investment of resources are more likely to be executed within an organization than those that require large amounts of resources. Therefore, the scale assigns 0 to the interventions that represent no costs at all, and 3 to the actions that ask for large quantities of resources.

The following is a brief exploration of some of the type of resources that can be considered for the evaluation of this particular item:

- **Economic resources:** The amount of capital or cash that the particular redesign action demands
- **Human resources:** The amount of people required for the execution of the redesign
- **Time:** The amount of time that the project demands for its execution

According to the availability of these resources, the company can consequently determine what value corresponds to the identified total.

#### 4.1.1.3 Evaluation of location level:

This item in particular refers to the level of the interaction that can be subject of a redesign action, meaning its position in the Technical Organization Chart. The assumption in this regard is that actions implemented at a lower level of the chart are generally easier to perform and have a lower technical complexity than those taken at higher levels.

In this sense, if the interaction occurs at a sub-component level –or lower, if the such is the case–, the value assigned to it is 0.

If the redesign must take place at a component level, the value to assign is 1.

When the redesign action is located at the level of an interaction that occurs among two subsystems, the corresponding value is 2.

When the redesign efforts must be focused at the level of the overall system, consequently, the value is 3.

Finally, if an interaction involves elements from different levels (for example, a sub-component and a subsystem), the score corresponds to the element located at the higher level.

The ultimate goal of setting this scoring process is to assign a weighed value to every  $k_j$  according to the performance of the specific interaction in relation to the set criteria. Therefore, having established among all the possible arrangements of  $k$ , which of them has a higher coefficient, the selection of the interaction to be redesigned appears clear.

Based upon the previous rating, the coefficient of a particular  $k_j$  can be calculated as follows:

$$ck_j = \frac{[(w1 \times I) + (w2 \times C) + (w3 \times L)]}{3} \quad (4.2)$$

Where  $I$  corresponds to the value of the interaction effect,  $C$  refers to the value assigned to the cost if intervention,  $L$  is the value of the location level, and  $w1$ ,  $w2$  and  $w3$  correspond to the weights assigned to each criterion.

According to this,

$$\sum_{i=1}^3 w_i = 1 \quad (4.3)$$

It is important to note that the weighing has to be determined according to the priorities of each organization, and this factor has an impact in the accuracy of the selection of the most relevant interactions for redesigning.

It is also relevant to clarify that both the mathematical calculation of the interactions and the scoring of their impacts can be sorted out quickly and might not be demanded in such an exhaustive manner when the expertise of the designer or the resources available point out easily where in the system the problem occurs. However, in cases where the problem does not seem evident, it is recommended to follow this approach, and gain expertise through its implementation.

#### 4.1.2 Problem formalization

Having determined, with help of the previous evaluation process, where the main problems occur in the system, the next step is to select where to focus the redesign efforts. As it has

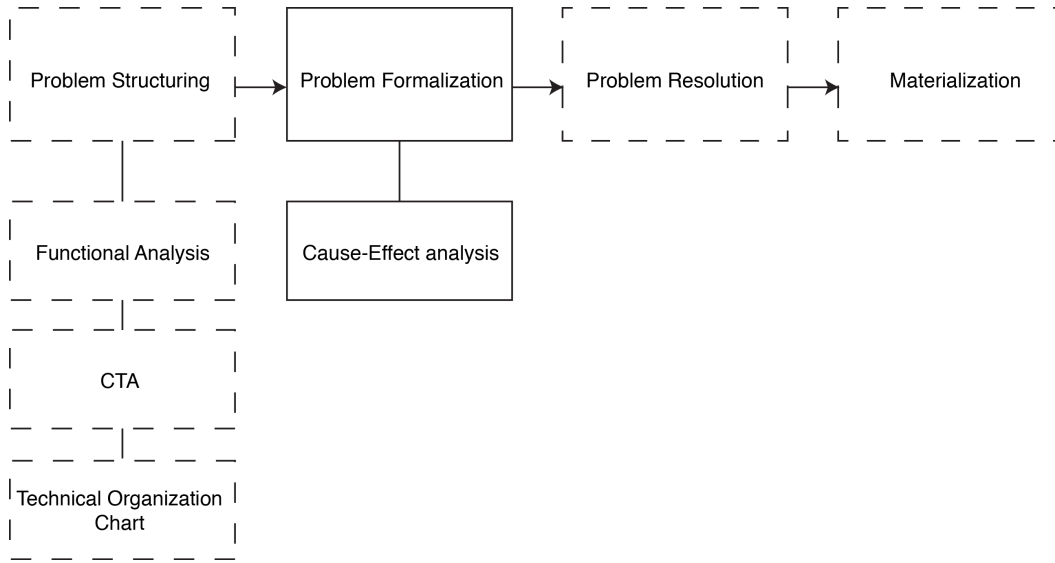


Figure 4.6: Problem formalization: Tools

been previously stated, it is the system or systems with the higher coefficient the ones that must be rethought towards a better performance.

At this point, the goal is to set a number of ways in which the identified problem or problems can be solved. In consequence with the analysis made in the previous stage, the designers must select the interactions between elements to be redesigned –one at a time– and disaggregate them.

The tool suggested for this particular stage is the Cause-Effect approach. (See Figure 4.6)

This approach fundamentally poses that every problem can be disaggregated into the following components:

- A first subsystem (S1), which originates the problem. This element can also be disaggregated into 2 sub-components:
  - The generation, meaning the element that creates the problem,
  - The transmission, which is the element that conducts the effects of the problem to S2
- A second subsystem (S2), the element that suffers the consequences or effects of the problem

- A functional flow transmitted from S1 to S2
- An interaction flow derived from the existence of contact between S1 and S2

In this approach, the system S1 generates and transmits a functional flow to system S2. Depending on the type of interaction (with or without interaction components, meaning with or without physical contact among both entities), other types of flows, called interaction flows will emerge.

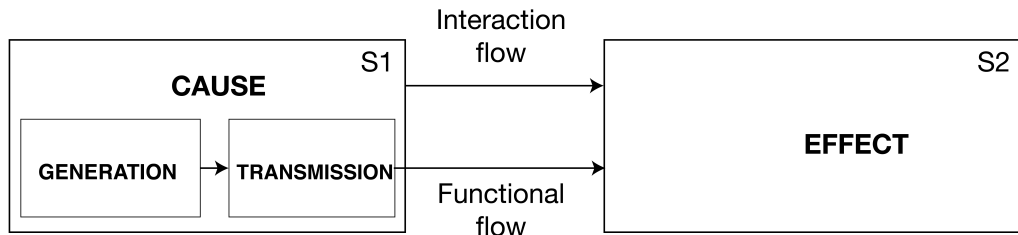


Figure 4.7: Cause-effect model

The functional and interaction flows between S1 and S2 will induce effects on the system S2, as shown on Figure 4.7. It is the analysis of said effects what will enable designers to determine whether there is a problem or not within the overall system.

The utilization of contents such as the one available in Table 4.2, for instance, can be of help for classifying and pointing out such effects.

In the Cause-Effect model, every effect has a cause. What is worth noting is that certain effects can be desired and useful in any particular system, but others are not desired and consequently detrimental. Therefore, the problem can come from any of the following configurations:

- A desired effect is insufficient
- A desired effect is not produced
- An undesired effect is produced

The crucial aspect at this point is that the expression of each of the heuristics must be comprehended by a diverse typology of users and must be adaptable to different kinds of systems.

Table 4.2: Produced and induced effects

State variables	Time variables	Produced effects	Induced effects
Force	Speed	Strain	Gap/Clamping/ Stresses/Vibrations
		Friction	Wear/Heat transfer/ Dilation/Retraction /Gap/ Clamping/Stresses/Creep
Pressure	Volume / Flow rate	Strain	Leaks/Stresses
		Friction	Dilation/Retraction/ Gap/Clamping/Stresses/ Pollution/Clogging
Temperature	Capacity rate	Heat flow	Dilation/Retraction/Gap/ Clamping /Stresses/ Creep/Icing
		Friction	Dilation/Retraction/ Gap/Clamping/Stresses/ Pollution/Clogging

This model will help designers get deeper insights on how and why the interactions occur between subsystems.

The first element to consider when using this approach is the classification of the flows that connect both entities, S1 and S2. In this sense, it is important to determine whether the system's flows correspond to matter, energy or signals. This discrimination will be helpful for the proper identification of where and why the design issues occur.

The effects caused by the interaction between said flow and the entities that it connects are the origin of most of the problems. Therefore, it is important to understand the impact that the action of the flows will produce. Once the nature of the flows is understood, the next step is to identify the following:

- Where in S1 is the problematic condition produced?

- How does S1 transmit said condition to S2?
- How do S1 and S2 interact? Do they make direct or indirect contact?
- How does S2 reflect the actions that S1 transmits?

This information will enable the designer to construct the Cause-Effect model, which will give the designer an overview on how the source and the receptor of the problematic flows relate to each other. At this point, the next stage is to determine what specific effects are produced in S2 by the flow coming from S1 –which is intrinsically related to the questions posed above, and in particular with the latter– and the induced effects that are derived from them.

The evaluation of the impact of the induced and produced effects will determine the kind of action required for the solution of the problem [Pailhès et al., 2007]. This means that the designer can choose whether to act on the generation, transmission or interaction of the problem within the system, or in the overall system itself, in order to avoid the occurrence of detrimental effects. From this point on, the designer can relate the situation to the heuristic hierarchy, therefore implementing heuristic rules to solve the problem under question with the purpose of taking action over the identified effect.

### 4.1.3 Problem Solving

As it has been previously stated, the present research proposes the incorporation of a set of 78 heuristics arranged in a branched structure, so as to enable the designers to explore the different strategies according to the characteristics of the problem.

For this particular stage, we suggest the utilization of an online platform that consolidates said heuristics and their respective application examples.

The following is the approach suggested for the utilization of the heuristics:

- Determine the desired kind of action to be taken over the problem: (a) eliminate, (b) reduce, (c) exploit or (d) displace the problem
- Locate the efforts of said action in a particular point of the system, understood from the perspective of a cause-effect model: (a) the flow or (b) the system. If the designer chooses to take action over the system, the specific location of the action must also be defined (generation, transmission, interaction, or the overall system itself)



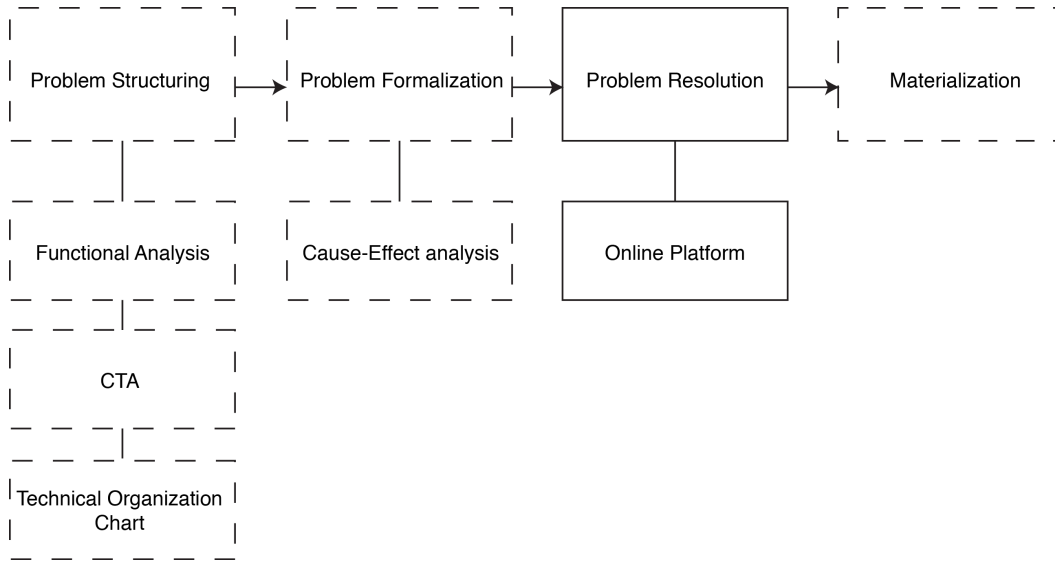


Figure 4.8: Problem resolution: Tool

- Select, from a range of possible strategies contained in the tree-like structure, what kind of specific action does the designer want to implement for the achievement of the set goal. The choice made depend largely on the possibilities of the system itself, the capabilities within the company and the skills of the designer.
- A consecutive set of choices will drive the designer through the branched structure, all the way to a final, highly specific heuristic strategy presented in the shape of a full sentence, that offers a particular functional principle to be explored and implemented into the creative process. This functional principle is explained by a physical or mechanical concept that describes the operation of the heuristic, in order for designers to fully understand the range of possibilities contained in the rule. This will, in principle, give a better guidance regarding functional aspects of the design.

#### 4.1.3.1 Online Platform

For the last step of the resolution process, as it has been discussed before, this research proposes the use of heuristic cards. In order to make these cards widely usable, we have created an online platform available at [mcalles.wix.com/heuristicstree](http://mcalles.wix.com/heuristicstree), that enables the use of both the tree and the cards in a user-friendly way.

Fundamentally, the online platform consolidates the 78 heuristic rules, proposing an in-

teraction alternative that enables designers to question themselves what specific actions they want to perform on the particular redesign process that is being carried out.

Figure 4.9 displays the workflow that designers must follow while using the platform, in order to identify and implement a strategy that solves a particular situation.

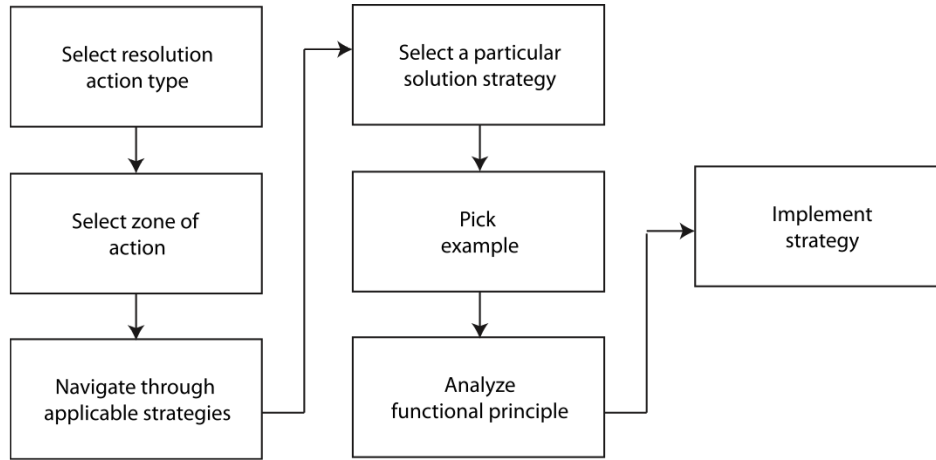


Figure 4.9: Software workflow

Before approaching the tool, designers must have outlined the specific problem they want to solve, and then they will be presented with heuristic rules that can eventually offer solution alternatives for that specific problem.

Following the structuring of heuristic rules detailed earlier in this chapter, designers are first questioned what specific action do they want to perform on the problem.

The second step, directly related to the Cause-Effect analysis, is to specify where in the system will the action take place. This choice has been grouped in two categories: (a) Flow and (b) Components, which encompasses the generation, transmission, interaction and overall system.

Afterwards comes a sequence of choices that guide designers through a number of possible strategies towards the solution of the problem initially set. At the end of this selection process, the implementation of the complete heuristic rule is shown in industrial and/or biological applications, that describe the principle that drives the heuristic under question.

#### 4.1.3.2 Software use: Example

The following is a detailed view of how the tool behaves in practice.

First, the user is presented with a home screen that invites them to make use of the tool. (See Figure 4.10)

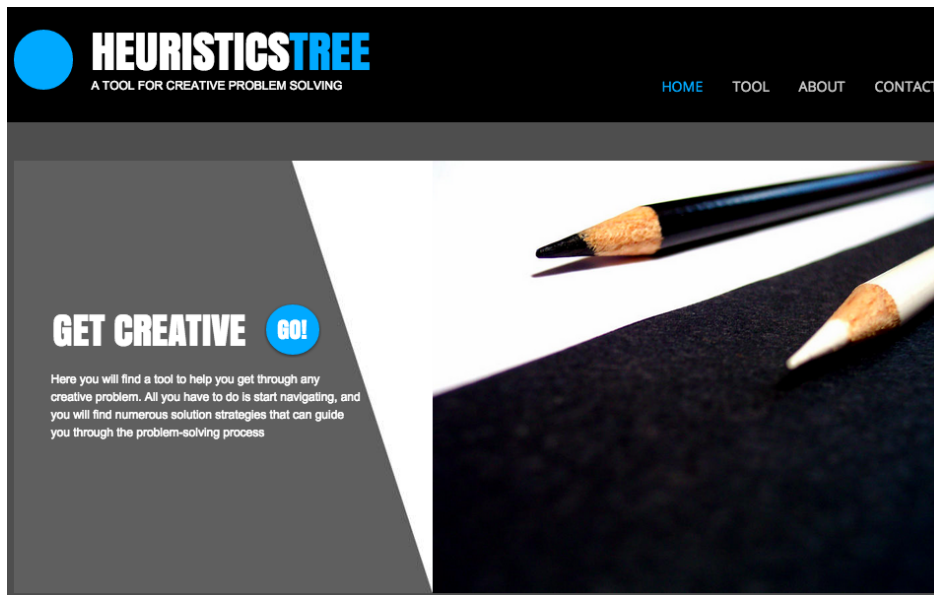


Figure 4.10: Software use. Home screen

In this home screen, the user will also find a search bar that will enable the use of a quick search, in cases where the user is already familiar with the way in which the tool works. In this search bar, key words to solution principles or variables will guide the user directly to a solution or set of solutions containing said keywords.

After getting started, the user is questioned about the way in which the problem will be approached, namely by acting on the flow or acting on the components. (See Figure 4.11)

In this case, it is assumed that the design engineer has selected to act on the flow.

Upon selection, the next screen shows specific action alternatives that will guide the designer to find a solution for the problem under question. In this case, after selecting action on the flow, three particular choices become available (See Figure 4.12).

The options available are:

- Through the modification of state variables
- Through the introduction of a previous, opposite action
- Through the modification of the nature of the flow

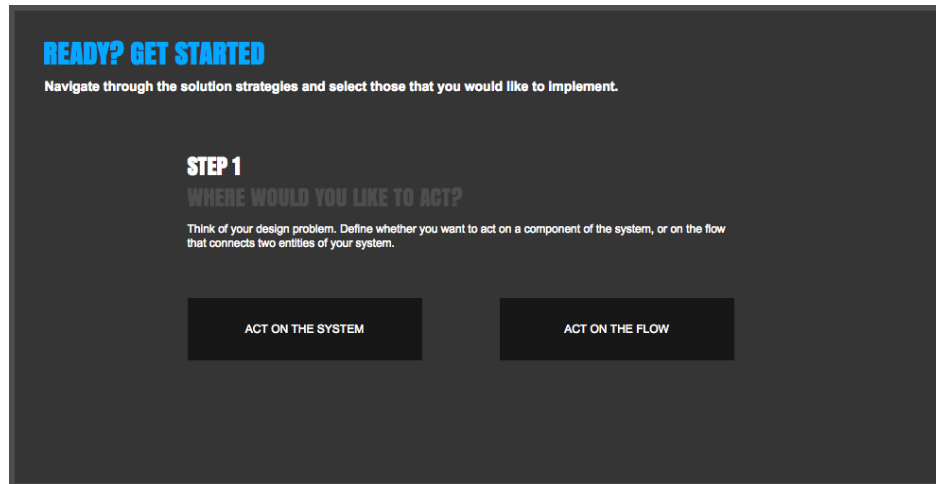


Figure 4.11: Software use. Step 1: Select area of action

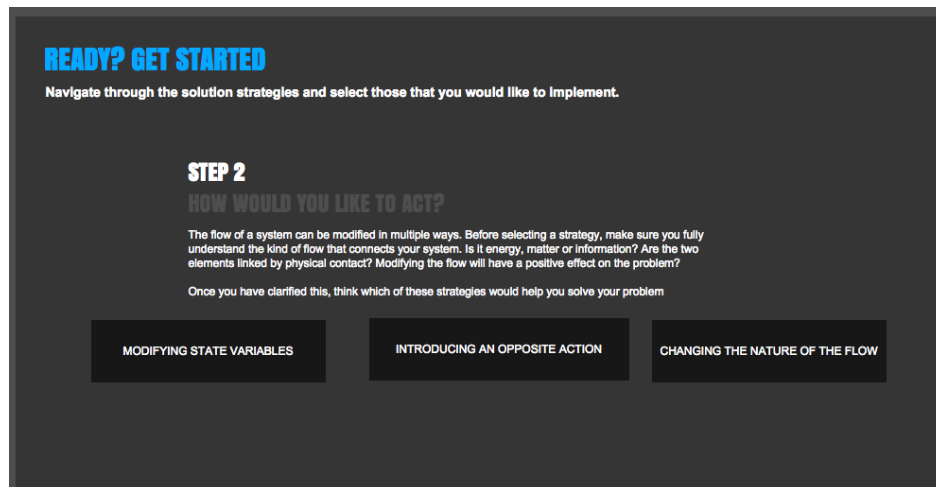


Figure 4.12: Software use. Step 2: Choose action alternative

Depending on the selected choice, further action possibilities are given upon selection. In the case depicted here, if the designer chooses to act on the problem through the modification of state variables, the software gives two additional choices: To act at either at a local or global scale of the system. (See Figure 4.13)

As it can be seen, each step is also accompanied by a brief description of the possible impact or important remarks to take into account when dealing with each new selection step.

Finally, once the design engineer reaches the end of the selection process, a set of examples shows up (See Figure 4.14).

These examples are obtained from different fields of applications, in general classified

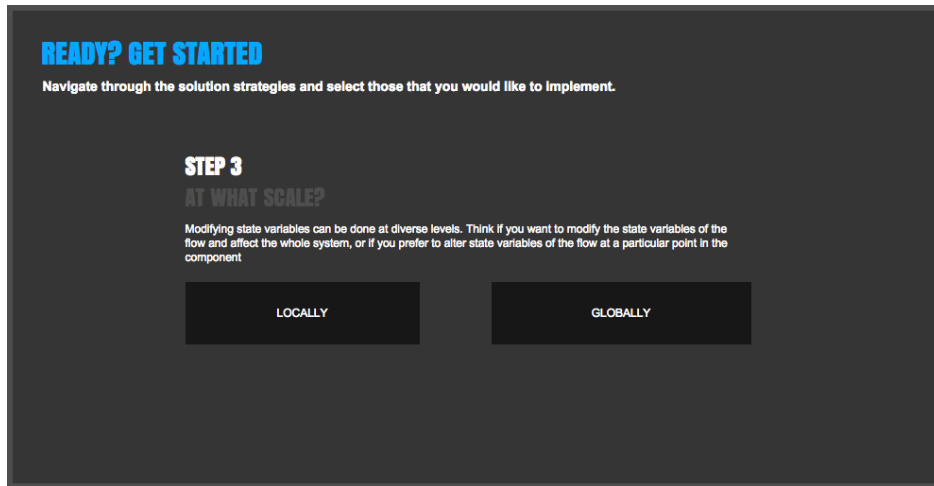


Figure 4.13: Software use. Step 3: Elaborate on action alternative

within three categories:

- Industrial applications
- Consumer products
- Biomimicry



Figure 4.14: Software use. Step 4: Solution examples

Each of the examples is presented in the shape of an image gallery. Therefore, if a particular application example draws the attention of the design engineer, it is possible to further explore said example by clicking on the gallery arrows.

Here, the user will not only find an explanation of the example, but also the functional principle behind it, expressed in the shape of a physical concept. (See Figure 4.15)

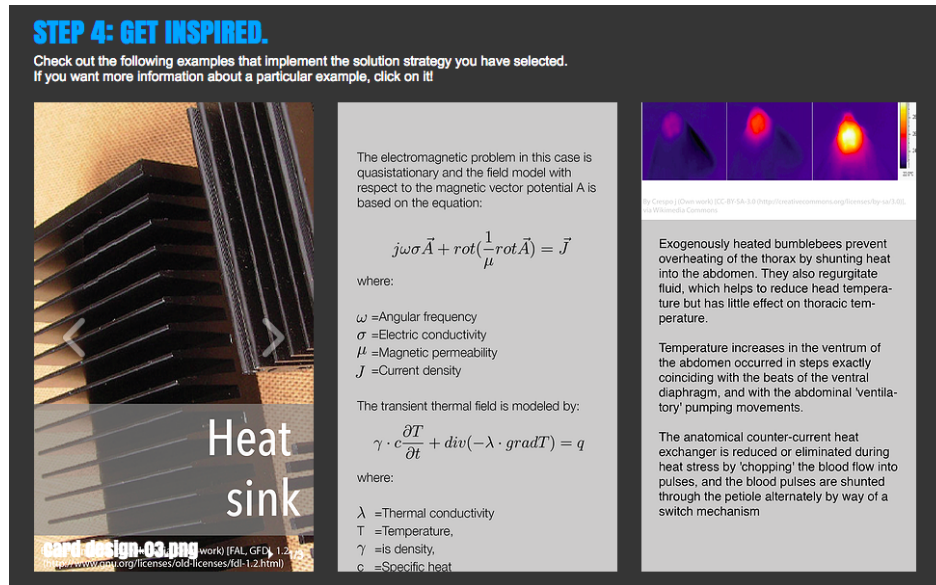


Figure 4.15: Software use. Example information

## 4.2 Capitalization of knowledge

Aside from providing a structured approach towards the usage of heuristic rules, the research also focuses in ensuring that emerging knowledge will be preserved and become tangible for future reuse.

This means that, whenever a design process leads to the creation of new or meaningful knowledge, the organization counts with a method that enables the incorporation to said knowledge to the knowledge base provided by this study. At this point, it is important to note that determining the level of novelty of the generated knowledge is subjective; what matters is the relevance this knowledge has for the organization in particular, and whether preserving it adds any value to the habitual operations of said organization.

The following is the suggested procedure for the capitalization of knowledge. (See Fig-

ure 4.16)

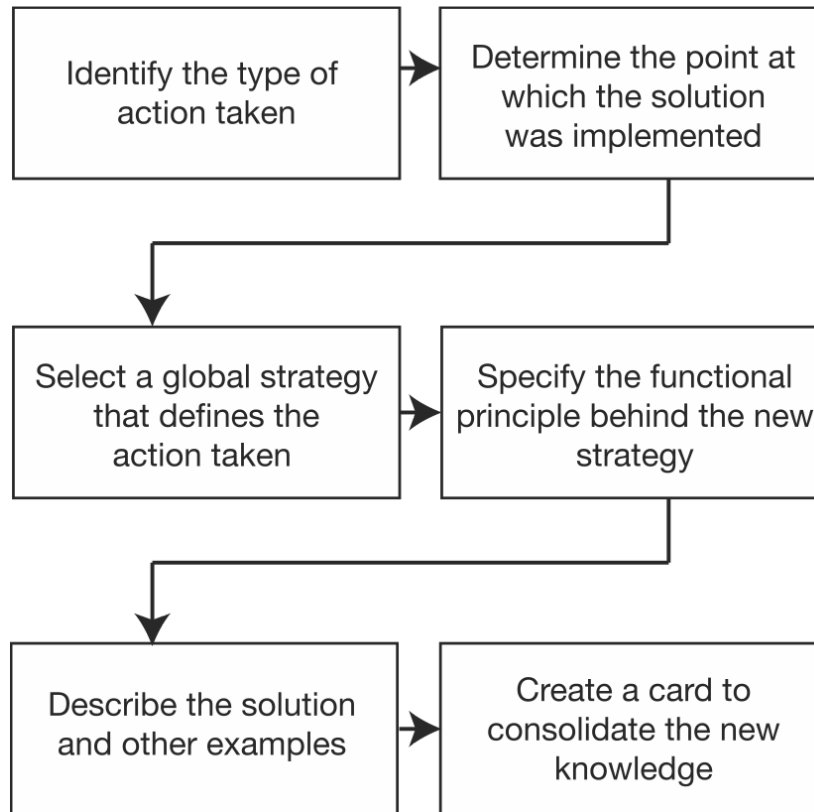


Figure 4.16: Capitalization of knowledge: Approach

First, it is important to analyze the recently solved design situation under the light of the method proposed above, in order to create a common ground for the desired integration. In this sense, the designer must identify what kind of action explains the redesign activity – namely, eliminating, reducing, displacing or exploiting the problem –and where in the redesign process did the action take place, from the perspective of a cause effect model –generation, transmission, interaction or effect of the problem.– This definition will serve to identify where the new knowledge will be located in the arborescence.

The next step is to define which of the global strategies describes best the kind of action taken during the redesign, in order to select a particular branch to accommodate the new rule. The goal is to determine at what level do the existing rules describe the new solution, and how to formulate the remaining sections of the heuristic rule. The definition of a global principle will also be helpful for the understanding and framing of the specific functional principle that describes the strategy, which will enable the completion of the sentence that

corresponds to the rule.

Finally, it is important to develop the practical tool that will serve for future processes; in this case, the card. Following the guidelines of the card, it is required to describe the present solution in terms of the physical phenomena that define it. It is also suggested to identify other examples of this solution in different domains (e.g., biomimicry and industrial design), which will help to better understand what the solution entails.





## Chapter 5

# Validation and Results

### 5.1 Methodology

In order to obtain relevant data for the improvement of the methodology and the tools associated with it, a number of preliminary case studies have been carried out.

The selection of case studies as a means for assessing the results obeys to the purpose of understanding the impact of the tool in design processes from a qualitative perspective and providing rich insights that can later be transformed into hypotheses, rather than concluding and generalizing the observations [Baxter and Jack, 2008].

In this sense, the case studies that will be detailed below, were by definition "multiple", given that they intended to verify the behaviour of groups around the modification of a single variable –in this case, the usage of a particular tool–, and "instrumental" because they were performed with the goal of refining a particular idea or hypothesis; in this particular case, the belief that the use of heuristic tools can improve the quality of the results of a particular design process. [Stake, 1995]

These case studies consisted of design teams developing quick design exercises, both with and without the implementation of the methodology and the tool.

The goal of these exercises is to compare the results obtained in said two scenarios – with and without heuristics–, and derive insights related to the benefits or limitations of the implementation of heuristic rules in the design process.

The following sections will describe in detail the setup of the exercises performed, along with their results and conclusions.

## 5.2 Validation method

In order to evaluate the tool developed within this study, two separate pilot cases were carried out.

Both studies were executed with a number of design teams or individuals. In each of the exercises, these designers were given a relatively simple redesign task within a certain context. The purpose was to compare the results of the teams and individuals, in regard to different indicators of performance, such as time invested, number of alternatives and overall quality of the design outcomes.

Further detailing on the specific indicators and design tasks developed during the exercises will be given in the following sections.

## 5.3 Validation study 1

The first validation exercise was carried out once the general methodology was outlined and during the first stages of the development of the support tool.

### 5.3.1 Validation objectives

The goals of this first exercise were:

- To evaluate the structural coherence of the proposed method and review its clarity and relevance in the context of a design exercise.
- To determine whether the usage of the proposed method represents possible advantages in the execution of design activities.
- To obtain feedback related to the support tool, in order to identify possible improvement areas.

### 5.3.2 Validation setup

With the previous goals in mind, the selected teams were delegated the task of redesigning a faulty coffee maker. The exercise was set up as follows:

- An initial experiment was carried out with three different teams, who approached the task using familiar design techniques and their performance statistics would be taken as a reference or benchmark for further evaluation.
- A second experiment was developed with three additional teams who followed the approach proposed in the present research and implemented in their process a given set of heuristic rules.
- Each team performed the task separately, in order to avoid external influence in the process. With the same purpose, each designer participated in only one experiment.

In the subsequent sections, a brief description of the process followed by the design teams will be described.

### 5.3.3 Experiment 1.1: Benchmark

The first experiment, as mentioned above, involved the participation of teams that did not follow the methodology proposed by the present research. Instead, they used an approach based upon their previous knowledge and experience in design methods; in general, the approach consisted of the following steps:

- Detection of issues in the coffee machine through the execution of a brainstorming process
- Functional analysis and component selection
- Product architecture
- Concept generation and evaluation

In most of these cases, the result was a formal redesign that attacked some of the problems spotted in the brainstorming process, but the level of depth of the technical detailing was merely superficial. Evidence of this will be provided in Section 5.3.6.

### 5.3.4 Experiment 1.2: Heuristic rules

The three teams that participated in this experiment were instructed in the use of heuristic rules in the creative process and were given a general overview of the proposed methodology.

With this input, all of the teams began with the identification of components and external factors that have an incidence in the product, through the development of a Functional Analysis and a CTA analysis (See Figure 5.1).

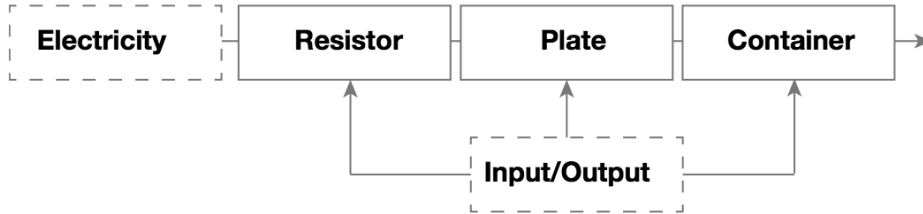


Figure 5.1: Experiment 1.2: CTA Analysis Example

Afterwards, they carried out a a Technical Organization Chart, of which Figure 5.2 is an excerpt from one of the teams. With this visual representation of the product, they were able to spot problematic areas at different levels of the product.

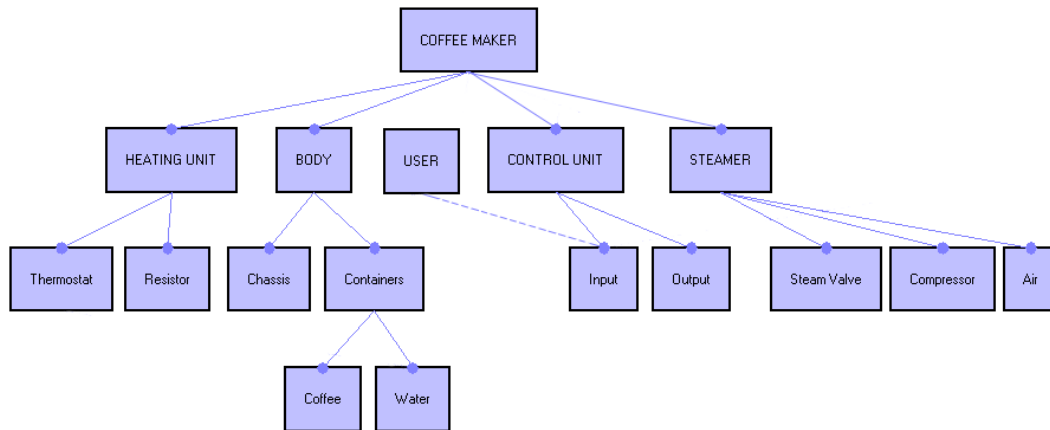


Figure 5.2: Experiment 1.2: Technical Organization Chart Example

In particular, the design issues that the teams encountered can be classified in three different categories:

- Poor physical interactions among components (adjustment between parts)
- Conflicts in variable management (temperature isolation and control)
- Poor signal management and user interface problems.

Once the main design issues were identified, the teams conformed a set of functional blocks through the usage of the Technical Organization Chart (See Figure 5.2). Then, they defined and classified the interactions between the components involved in the problematic situations detected earlier, as well as the flows that connect said blocks.

At this point, the analysis of the number of possible interactions (Equation 4.1) was carried out. In the case depicted in Figure 5.2, for instance, 120 possible interactions resulted from the analysis. However, given the preliminary character of the exercise, the prioritization process did not take into account all the interactions, but only those directly related to the problems spotted in an earlier stage of the process.

In this sense, the teams listed and weighed the interactions according to the approach proposed in Equation 4.2. An example of this evaluation is shown in Table 5.1

Table 5.1: Interaction evaluation: Example

INTERACTION	VARIABLE	W	RATING	TOTAL
Resistor - Container	I	0.6	1.8	0.87
	C	0.1	0.2	
	L	0.3	0.6	
Chassis - Container	I	0.6	1.8	0.87
	C	0.1	0.2	
	L	0.3	0.6	
Water - Container	I	0.6	1.2	0.63
	C	0.1	0.1	
	L	0.3	0.6	
Input - Output	I	0.6	0.6	0.50
	C	0.1	0.3	
	L	0.3	0.6	
Coffee - Water	I	0.6	1.8	0.77
	C	0.1	0.2	
	L	0.3	0.3	

According to the evaluation, the higher scoring interactions were later analysed under the

perspective of a cause-effect model, helping the design engineers to define where to locate the redesign effort.

In the case displayed in Figure 5.3, for instance, it became apparent for this particular design team that one of the main issues was the deficient heat management, caused by a poor isolation of the resistor, which generated deformations in seals and casings.

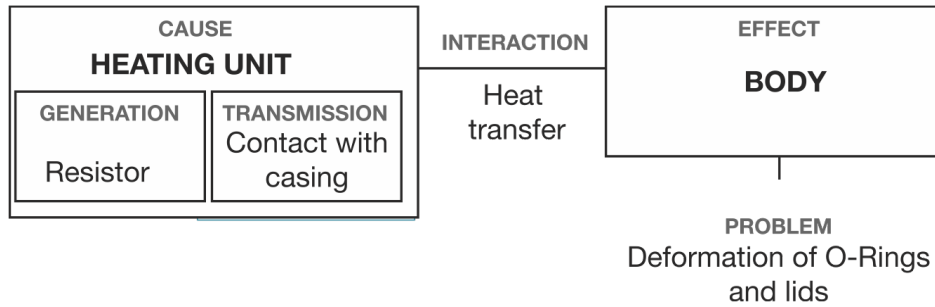


Figure 5.3: Cause-Effect model Example

Once the teams selected whether to act on the generation, transmission, interaction or effect of the selected problems, heuristic rules were implemented. The decision on where to locate the actions enabled the design engineers to approach the heuristics tree –in this case, a shortened version with 9 different branches– Each of the branches conducted to one of 9 cards like the one depicted in Figure 3.6, each of them detailing a different functional principle. The teams studied the tree and the cards, associating them to their particular case through interpretation, and selected those which could be easily related to their problem.

Some of the functional principles identified and selected by the teams as a possible solution strategy were:

1. The modification of state variables at a local scale –in this particular case, temperature–
2. The segmentation of a component into layers or the use of multi-materials
3. The evolution of a system through the incorporation of porous media.

Each of these principles selected is related to a specific heuristic card, as seen in Figure 5.4

Afterwards, the design engineers moved on to the generation of solution alternatives for each of the subsystems, eventually developing concepts as a result of the integration of the redesigned subsystems.

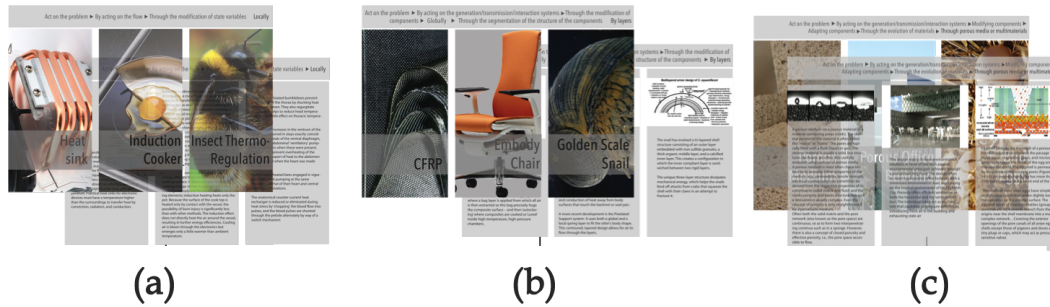


Figure 5.4: Example of cards selected

### 5.3.5 Redesign Outcomes from Experiments 1.1 and 1.2

Given that all participating teams carried out the same redesign task, –namely, take a regular coffee machine and redesign it based upon a product analysis– the differences between the resulting redesigns were comparable between each other from a visual perspective.

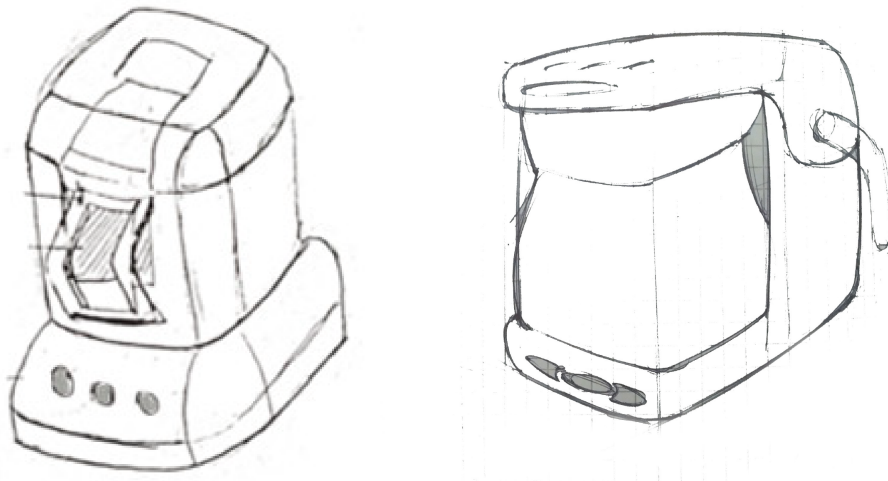


Figure 5.5: Redesign outcomes: Benchmark

The design concepts shown in Figure 5.5 display some of the results obtained by the design teams that used an unstructured approach for the design process. Figure 5.6 shows results obtained by the design teams that used heuristics.

Based upon observation, it is possible to see that the benchmark teams focused their redesign mostly on formal aspects and very little functional detailing was given, as it has been mentioned before. Meanwhile, all concepts presented by the teams that implemented heuris-



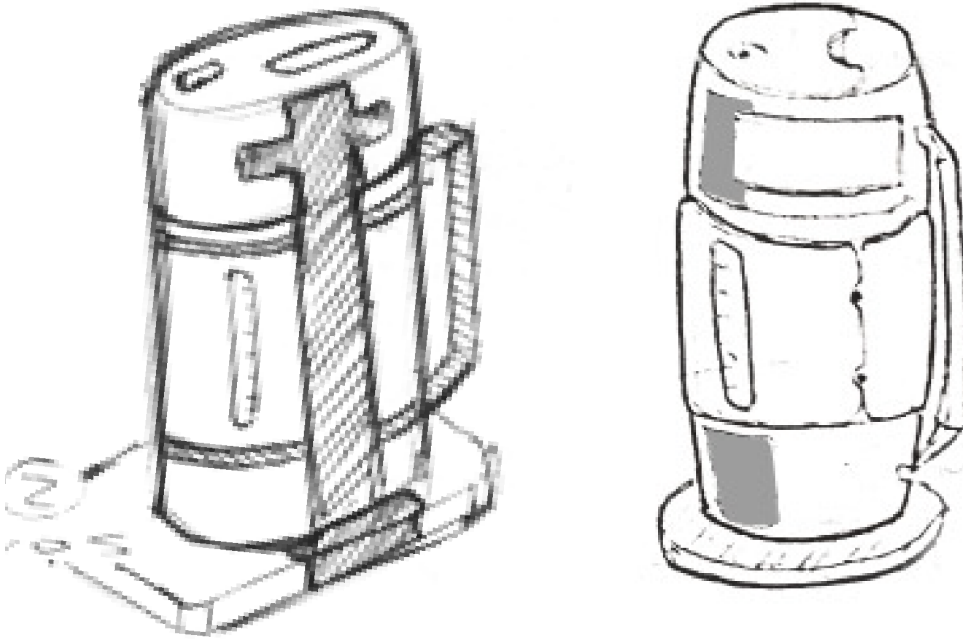


Figure 5.6: Redesign outcomes: Heuristics

tics show redesign efforts in diverse subsystems of the product, creating a particular product architecture that can be considered responsible for the final shape and general appearance of the design. The subsystem approach, which occurred in every case with the implementation of heuristics, can be observed in the annotations and zoom-ins that accompany their designs. An example of the detailing level can be seen in Figure 5.7.

The design alternatives developed by the teams that implemented heuristics show clearly how the rules were implemented in the process, with the purpose of solving the problems that had been identified in earlier stages.

For instance, in Figure 5.7 the incorporation of thermal jackets appeals to the heuristic rule that suggests the evolution of the system through the incorporation of layers. Similarly, the transformation of the heating unit through the implementation of induction heaters relates to the heuristic that proposes to modify the state variables of a system at a local scale.

The detailing of the application of specific heuristic rules in the redesign is shown in Table 5.2, particularly setting the example of one of the teams that used heuristics.

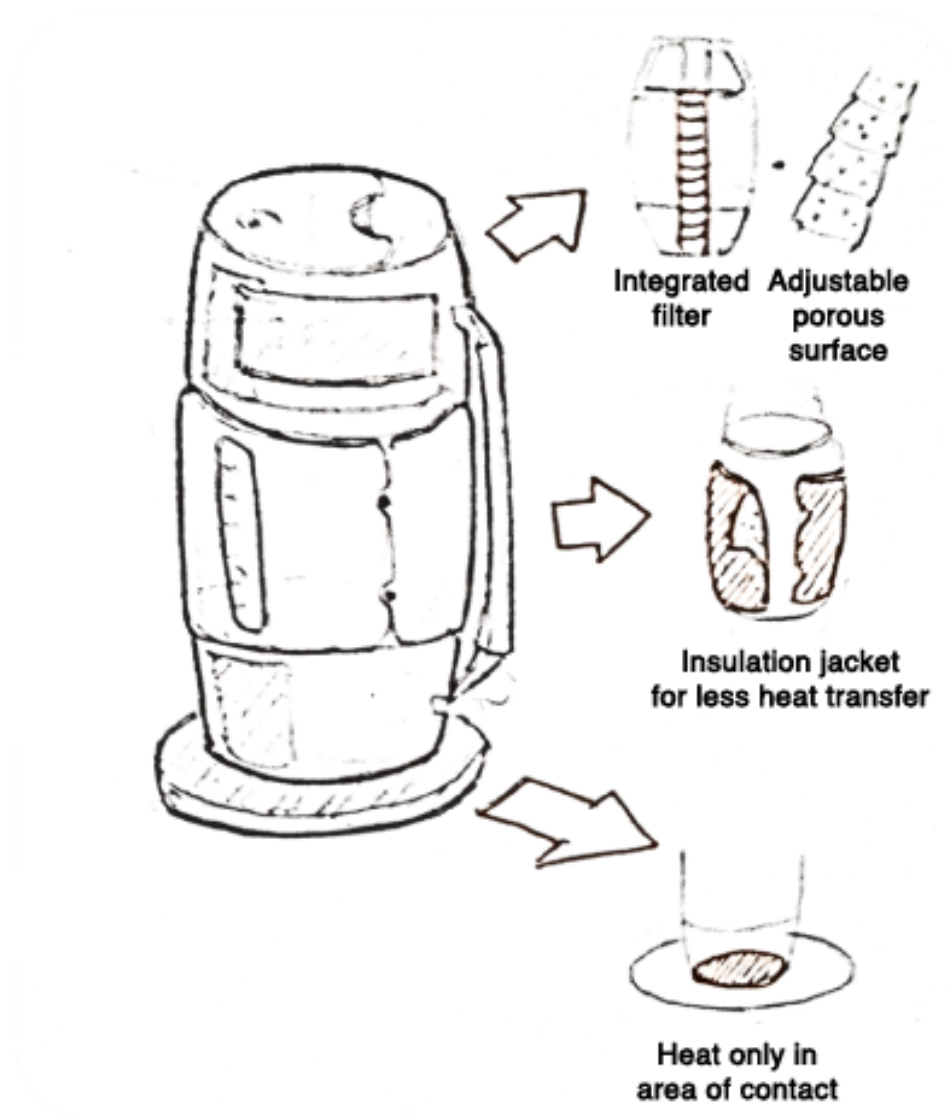


Figure 5.7: Redesign outcomes: detail

As it can be seen, the outcome reached by the teams that implemented heuristics, and the case shown in Table 5.2 in particular, displays the usefulness of heuristic rules in the redesign of diverse subsystems.

The comparison and evaluation of the redesigns will be further detailed in the following section.

Table 5.2: Heuristic rules in the redesign: Example

<b>RULE</b>	<b>OBJECTIVE</b>	<b>APPLICATION</b>
"Act on the problem - By acting on the flow - Through the modification of state variables - Locally"	Improve temperature control and avoid heat transmission to other elements	Use of induction heat platform for fluid heating
"Act on the problem - By acting on the generation/ transmission/ interaction/ system -Through the modification of components - Globally - Through the structural segmentation of components - By layers"	Prevent fluid heat loss after power off	Incorporation of thermal jacket for temperature isolation
"Act on the problem - By acting on the generation/ transmission/ interaction/ system -Through the modification of components - Through adaptation of components - Through evolution of materials - Towards porous materials or multimaterials"	Eliminate removable components that deform with heat	Design of porous permanent filter

### 5.3.6 Experiment Results

As it was shown before, the design approach of both subgroups was significantly different. However, an analytic process helped the researcher to identify how the key dissimilarities reflect in the final results and how can these differences be related to the implementation of heuristic rules. Furthermore, it helped in spotting possible benefits and disadvantages of said implementation.

The first and more evident difference is related to time management throughout the

process.

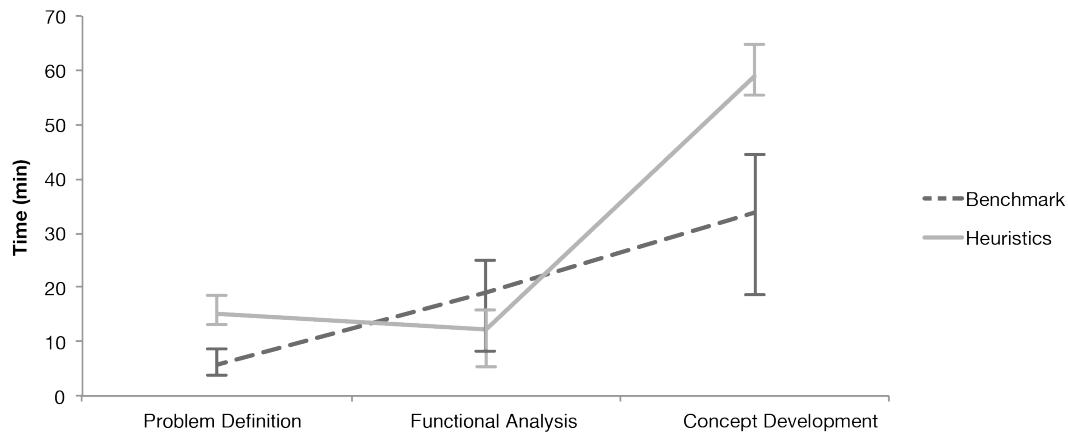


Figure 5.8: Results: Time performance

The results, as seen in Figure 5.8, show that the teams that approached their task with the implementation of heuristics spent, on average, a very similar time in structuring the design problem –meaning, Problem Definition and Functional Analysis– with teams that implementing heuristics spending on average 8% more time. However, the heuristics teams spent 36.99% less time in Functional Analysis itself, in comparison to the benchmark teams. It is also worth noting that the benchmark teams spent 42.95% less time in the conceptualization stage than the average of the other teams.

The analysis goes in line with the results shown in Section 5.3.5, where it becomes evident that the level of detailing reached by the teams that implemented heuristics was significantly higher than that of the benchmark team, which can also be seen in Table 5.3.

As it was mentioned before, the design approach of both teams was significantly different; while Benchmark teams in general made a strict differentiation between functional and formal aspects of the design, the teams that used heuristics deepened in the functional aspects, which determined the appearance of the product. This is reflected in the amount of concepts generated; while benchmark teams developed a larger number of formal concepts, the teams with heuristics generated less concepts, but each of them with a larger number of subsystems redesigned. This, of course, is derived from the approach by subsystems that the methodology proposes, which helps design engineers get a better overview of the design problem from a functional perspective.

In general, the study suggests that, when exposed to heuristic tools, design teams can

Table 5.3: Experiment Results: Comparison

VARIABLE	BENCHMARK			HEURISTICS		
	A	B	C	D	E	F
Total time (min)	77	30	68	89	85	83
No. of problems identified	8	3	6	8	10	9
No. of functional blocks identified	11	6	9	9	10	9
No. of product architectures developed	1	1	2	2	1	1
No. of concepts generated	4	2	2	1(6)	2(5)	1(3)

reach more detailed functional concepts, thus opening the possibility of saving time and effort in the subsequent stages of the process because fewer efforts are required in adjusting functional and formal solutions to a same design problem.

However, it also showed limitations in the implementation of the support tool given that at this point designers did not count with enough information regarding the selection process of specific heuristic rules. This occurred mainly because the heuristic cards were provided physically, and it was unclear how they were related to the heuristic tree.

This is the main reason for performing a second validation exercise, in which the tool has been improved and completed, in order to provide a better support for the creative process.

## 5.4 Validation study 2

With these preliminary results, the support tool was incorporated into a virtual platform where a clearer navigability was expected (See Section 4.1.3.1) and a second validation exercise was carried out.

### 5.4.1 Validation objectives

The goals of this second exercise were:

- To evaluate the impact and pertinence of the Online Tool in terms of usability and functionality

- To conclude if the tool provides effective benefits when compared to regular, non-heuristic approaches.

In this case it is important to note that the goal was not to prove whether the methodology itself provides benefits in design outputs, since this was already evaluated in the previous validation cycle, but to assess the benefits specifically derived from the online platform.

In this occasion, the case study consisted on the redesign of a public light post, particularly devised for the rural, off-grid context. This specific situation posed diverse design issues, such as finding an adequate energy source, facilitating transport and installation, among others.

#### 5.4.2 Validation setup

The setup for this second exercise was planned as follows:

- All of the individuals participating in the study were Engineering students from 3rd year or above. All of them were briefed on the design specifications of the problem at hand. A total of 31 individuals participated in the study, distributed evenly between heuristics and non-heuristics approach.
- A group of individuals carried out the task without any further detailing; they used conventional approaches to come up with design solutions and they served as a benchmark for comparison against individuals using heuristics.
- A second group of participants was instructed in the methodology developed for the implementation of heuristics. They were also familiarized with the online platform as a support for the methodology, and they were asked to come up with solutions based upon the strategies that the software provides.
- Each person performed the task separately, in order to avoid external influence in the process. With the same purpose, each designer participated in only one experiment.

The following subsections describe the general procedure followed during the validation exercise.

### 5.4.3 Experiment 2.1: Benchmark

In a similar way as Experiment 1.1 (See 5.3.3), the individuals performing the redesign task without the use of heuristics followed familiar approaches, namely a brainstorming process for the detection of potential redesign areas, and a subsequent creative process for the generation of ideas.

In this particular case, given that the specific aspects of the design task were made very clear during a briefing session, the outcomes of the non-heuristic approach were focused on architectural redefinitions and functional innovations for light posts. Further exemplification of the solutions will be given in the following sections.

### 5.4.4 Experiment 2.2: Heuristic rules

For this exercise, participants were also briefed on the problem at hand and additionally, they were given an in-depth explanation on the method proposed and the online support tool to be used during the ideation process.

Students were given a template where a step-by-step guide indicated how to proceed on each of the stages of the methodology and the initial stages of the method were solved beforehand. This was done because, as it was said before in the definition of the experiment objectives, at this stage of the validation process the test was focused on proving the impact of the tool specifically, rather than the overall methodology, given that this had already been tested in the previous validation cycle.

### 5.4.5 Redesign Outcomes from Experiments 2.1 and 2.2

The images displayed in Figure 5.9 are the examples of two concepts for each of the scenarios. As we will see in Section 5.4.6.2, these two were the best rated concepts of all the validation exercise.

In general, from a qualitative perspective, the development level of all the concepts was not particularly high, meaning that all the ideas were presented superficially. This can be due to the fact that time was limited for the execution of the exercises and that the individuals participating on the process were not particularly savvy on the topic related to the redesign task assigned to them. However it was possible to detect certain benefits derived from the implementation of heuristics.

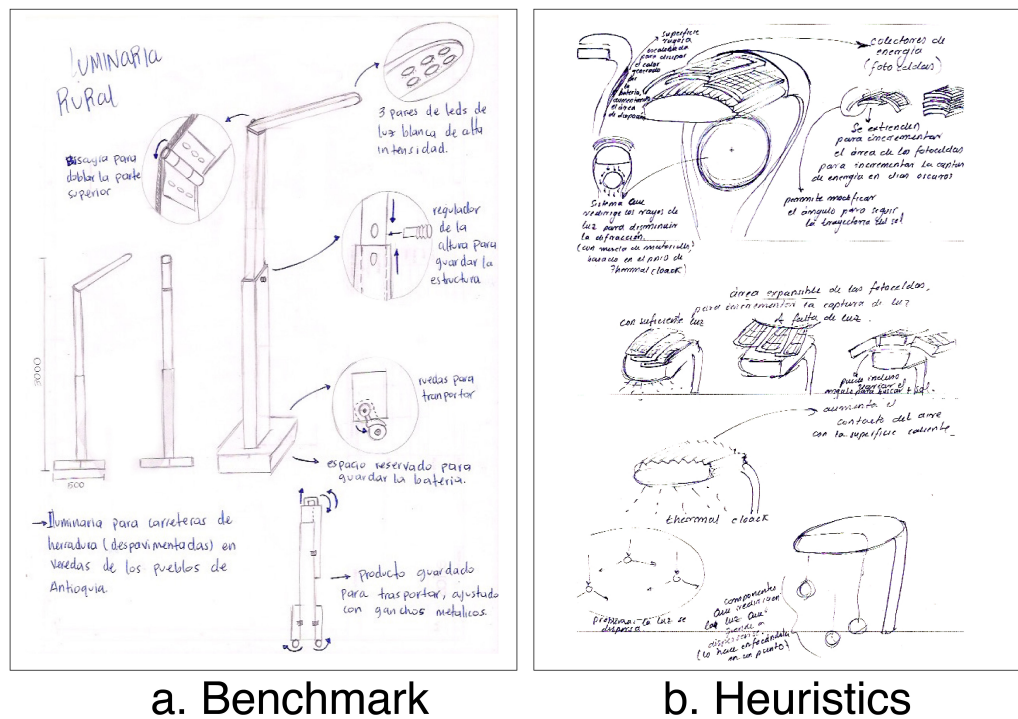


Figure 5.9: Redesign outcomes: Concepts

Again, the subsystems approach that is derived from the analysis of a product's hierarchy and the cause-effect vision, favored the level of depth displayed in the concepts that used heuristics. While in both cases the designers detailed their concepts, the concept developed through heuristics displays a much more technical approach.

This proved to be true not only for the best rated concepts in heuristics, as we will see in the following section, but in most of the cases. While benchmark concepts were barely detailed in terms of subsystems, nearly all the heuristics concepts were explained in detail functionally, even when the ideas were not fully evolved.

## 5.4.6 Experiment Results

### 5.4.6.1 Analysis of tool implementation

One of the key observations of this study is that the concepts that used heuristics showed a pattern of solution strategies that became common for many resulting ideas. In other words, solutions turned out to be very similar to one another in terms of functionality.

At the time of the test, 44 heuristic rules were available in the platform. Throughout



the exercises, a total of 15 rules were used in the concepts developed, meaning a 66% of the available rules were not considered for conceptualization.

Of the rules used, in fact, rule No. 28 was used 31% of the times, rule 26 was used 11% of the times, and rules 2 and 22 were used 8.8% of the times each. (See Figure 5.10). Therefore, the fact that 4 rules represented the 61% of all the heuristic rules used explains the similarity among concepts.

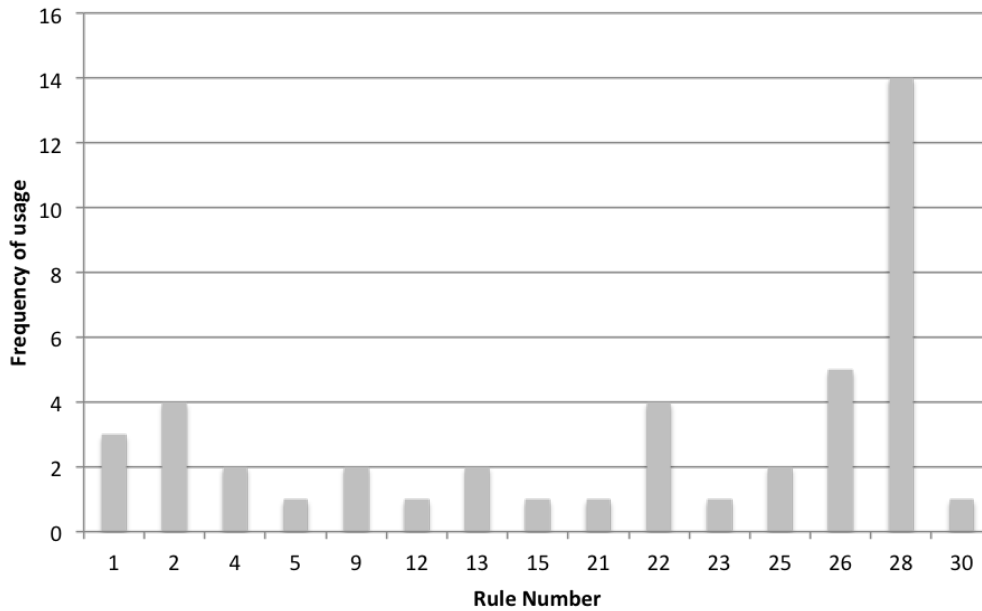


Figure 5.10: Repetitiveness of rule usage

It was not possible to identify whether this issue can be attributed to the setup of the exercise itself (by standardizing the problems to solve and providing a uniform format for the resolution of the task) or the usage of the tool (by providing the exact same examples to all the participants). This poses a question regarding the diversity of concepts achievable with the support tool and it is important to further dig into this matter in the future.

#### 5.4.6.2 Evaluation of resulting concepts

The resulting concepts were evaluated by a panel of 8 experts, who had experience in diverse areas such as product aesthetics, academic research and renewable energies, among others. The experts rated the outcomes based on five criteria:

- **Novelty:** The concept is original, new or uncommon within its domain
- **Feasibility:** It is possible to transform the concept into a product from a technical and manufacturing perspective.
- **Utility:** The concept provides a practical application for its domain.
- **Clarity:** The concept is well explained and visually informative.
- **Level of detail:** The concept is explicitly explored from a formal and functional perspective.

Four of these criteria were defined based on the approach proposed by Kudrowitz et. al, [Kudrowitz and Wallace, 2013]. A fifth indicator –level of detail– was included taking into account the observations from the first exercise, which indicated that the usage of heuristics provides a higher level of elaboration of the design concepts. In this sense, the intention was to validate said observation.

Additionally, after the concept results were obtained, each concept was scored, averaging all the individual criteria and the result obtained would be considered the overall quality of said concept.

It is important to note that, although some other concept quality indicators were considered for evaluation –such as the ones proposed by Shah et. al., [Shah et al., 2003]– these particular indicators were selected because they covered diverse aspects of concept quality without implying a direct formulation of a scale, which would likely cause a bias in the analysis of the concepts.

The experts evaluated the concepts on a scale from 1 to 5 for each criterion. This evaluation was performed without knowing which of them used heuristics and which did not. This was done with the purpose of avoiding biases and placing the concepts in an equal ground.

**Overall quality of the concepts:** A first result derived from the expert evaluation is that concepts that used heuristics have on average an overall quality 11.95% higher than those which do not implement the tools. Specifically, the overall score for heuristics concepts was 2.67, while concepts without heuristics scored an overall average of 2.07 (See Figure 5.11)

As a matter of fact, when compared against each other, the overall results show that concepts with heuristics outperformed the benchmark concept in almost every criterion. (See

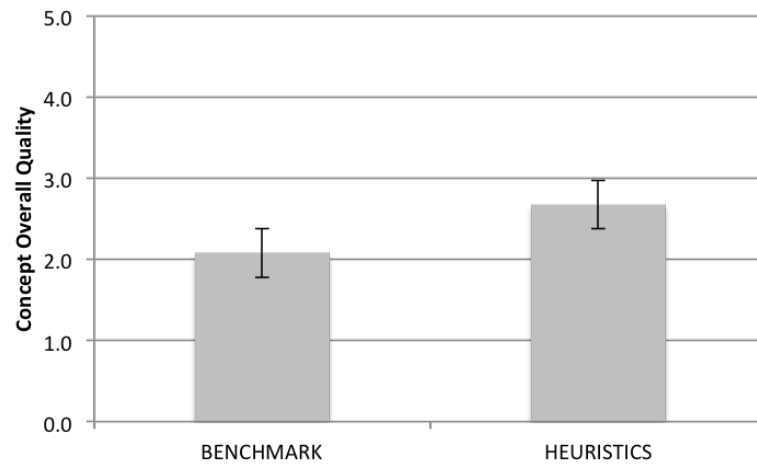


Figure 5.11: Results: Concept quality

Figure 5.12)

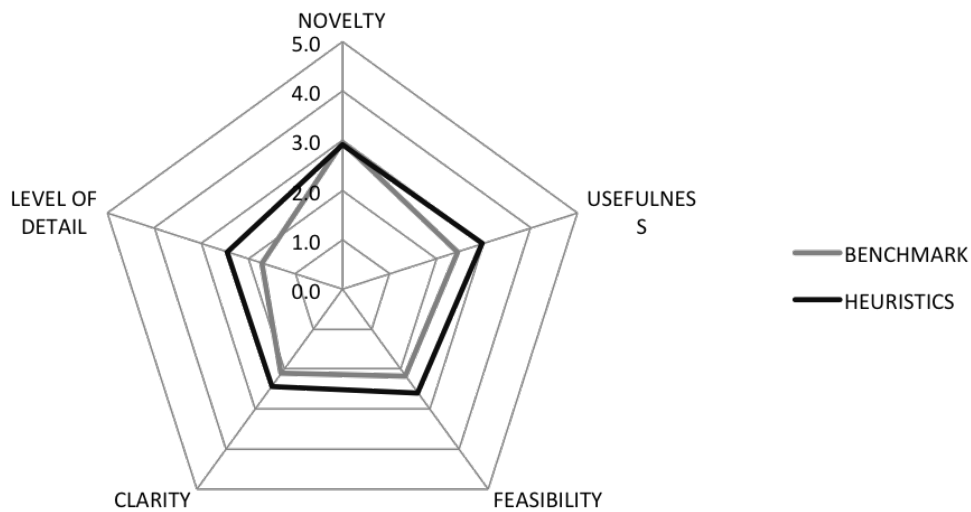


Figure 5.12: Results: Overall concept evaluation

It is possible to infer from the previously shown results that the usage of heuristic rules effectively influences the quality of the design concepts in a positive manner.

**Novelty:** In this particular variable no significant differences were detected between benchmark and heuristic concepts, scoring 2.97 and 2.92 respectively (See Figure 5.13). This can be attributed to the lack of technical knowledge of the participants, as it was mentioned before. This fact most likely directly limited how far-out could the participants envision their concepts.

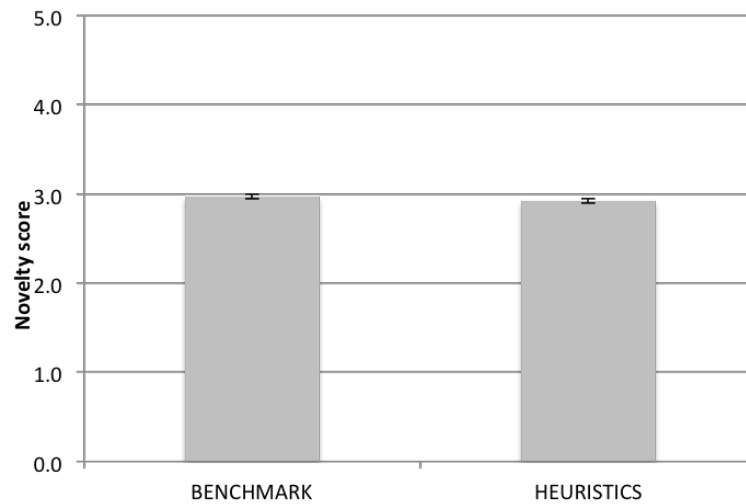


Figure 5.13: Results: Concept novelty

**Usefulness:** For this particular criterion, concepts with heuristic rules showed a better result than benchmark concepts. In fact, concepts with heuristics were deemed 10.41% more useful than benchmark concepts, scoring 2.97 and 2.45 respectively.(See Figure 5.14).

The hypothesis around this result is that the heuristic method invites designers to identify, analyze and propose solutions for practical problems by using the Cause-Effect approach, thus enabling them to come up with effective concepts that enhance the functionality of a product for a given context, making it in fact more useful.

**Feasibility:** In regard to feasibility, concepts that were developed using heuristics performed slightly better than benchmark concepts, scoring 2.59 against 2.17, meaning a score 8.45% higher. (See Figure 5.15)

Again, this is attributed to the methodological approach that designers followed for the definition of the concepts, which forced them to conceive practical solutions to the detected

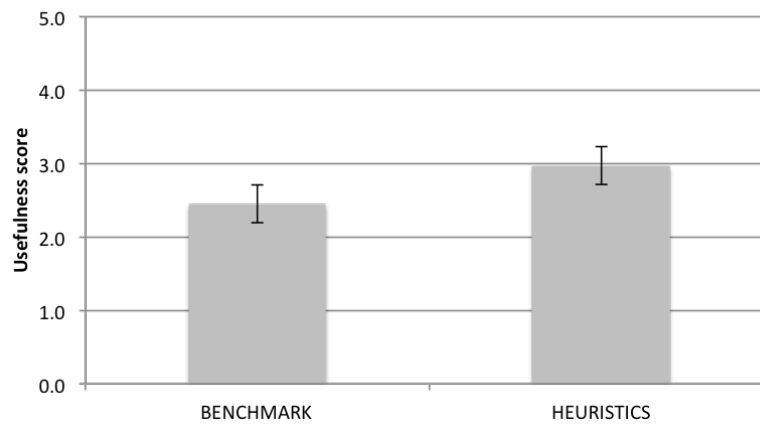


Figure 5.14: Results: Concept usefulness

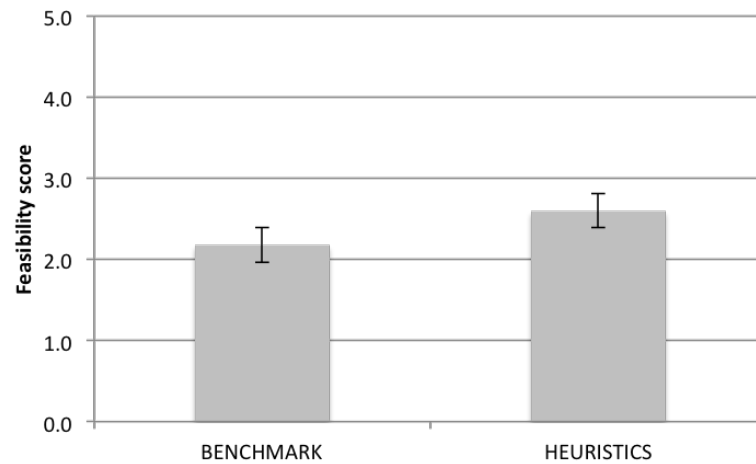


Figure 5.15: Results: Concept feasibility

issues and to explore their concepts from a functional perspective. Additionally, the fact that designers are exposed to practical applications of heuristic rules in diverse domains of knowledge through the heuristic cards contained in the online platform, and the subsequent interpretation of these applications, may lead to the implementation of feasible ideas derived from existing solutions.

**Clarity:** This item is intrinsically related to the designer's ability to graphically express and idea and convey a message through graphical means. Therefore, it is difficult to specifically relate the impact of heuristics in this particular aspect. However, the fact that concepts with

heuristics scored 6.5% higher –2.42– than benchmark concepts –2.10– (See Figure 5.16) might be a hint that since the method provides a deeper understanding of the design problem, it enables designers to express the concepts in a more specific manner, technically speaking.

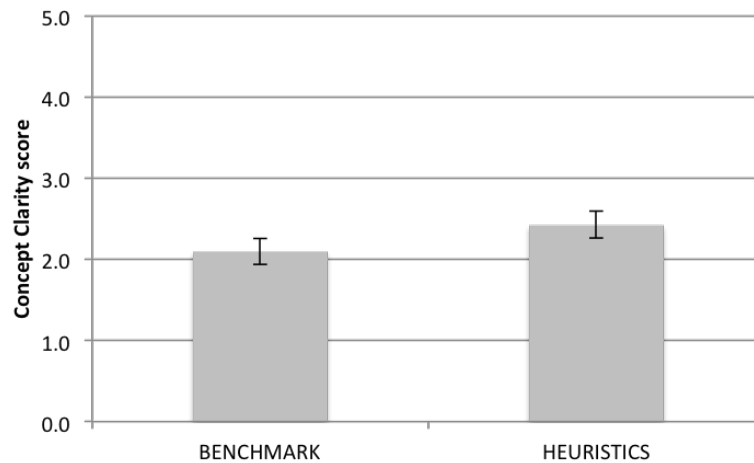


Figure 5.16: Results: Concept clarity

**Level of detail:** Perhaps one of the most interesting results is that concepts with heuristics outperformed the benchmark concepts by 14.99%, the former scoring 2.45 versus 1.70 of the latter. (See Figure 5.17)

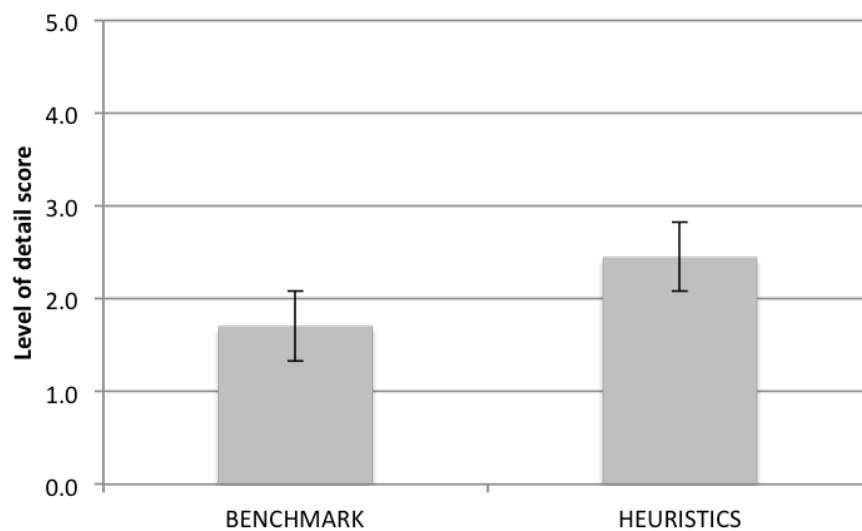


Figure 5.17: Results: Concept level of detail

This indicates that the methodological approach has an impact in the depth with which the concepts are conceived, derived from a richer understanding of the subsystems that conform the product under question.

#### 5.4.7 Tool evaluation

In addition to the execution of the exercise, the individuals who were using heuristics were asked to provide feedback regarding the online platform, in order to understand their perception of the tool and the perceived impact of its implementation.

For this purpose, they were provided with a short survey where they would evaluate two main aspects of the online platform: Usability, related to navigability and general user experience [Lee and Kozar, 2012], and Functionality, related to usefulness of the tool as support for the design process [Dalhousie, 2014].

##### 5.4.7.1 Usability

In order to evaluate the platform's usability, the users were asked to rate the platform in a scale of 1 to 5 regarding their experience with the following aspects:

- Website navigability: General ease of use of the platform regarding the ability to find information and to provide alternative interaction.
- Time invested in the resolution of design problems: Also understood as Task Completion time, it relates to the assessment of the time required to reach a specific rule that is applicable to the problem at hand [Roy et al., 2014].
- Intuitiveness of the navigation: Disposition of navigation controls, and clarity regarding how to approach the platform.

According to the users, the online platform has a highly understandable content structure, rating it with 4.3 in average on both navigability and intuitiveness. Similarly, the users considered that the time required to navigate through the platform was effective, judging by the average score of 4.0 obtained in this item. (See Figure 5.18)

In this sense, the results indicate that, although in some specific cases users manifested difficulties understanding how to proceed, in general the tool responded satisfactorily regarding user experience.

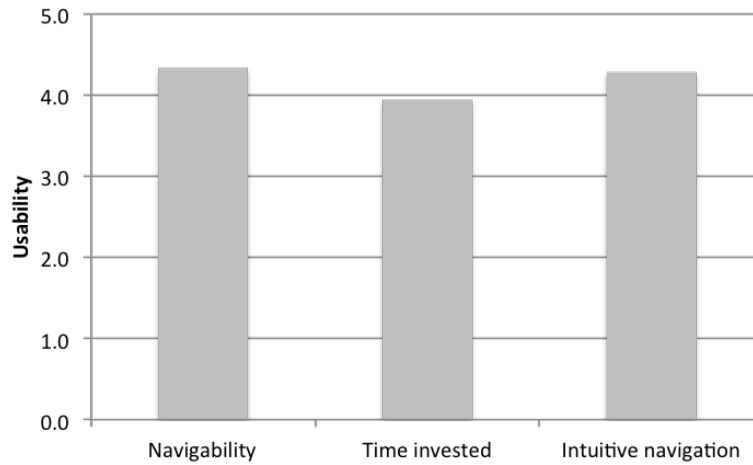


Figure 5.18: Results: Platform Usability

#### 5.4.7.2 Functionality

For Functionality, users rated the following aspects, again in a 1 to 5 scale:

- Usefulness of information found on the platform: Applicability of the presented examples to the activity of product design. This particular criterion refers to whether the participants can derive useful insights from the platform for their design concepts.
- Accuracy of the information provided: Clarity, pertinence and adequacy of the information presented in the examples and guide texts.
- Objectivity of the information provided: This item rates whether the users consider the information unbiased towards a particular rule or favoring a specific kind of solution.
- Assistance to decision-making: Contribution of examples to providing solutions and enabling interpretation of ideas for their application in design concepts.

The following are the results obtained in such evaluation:

Again, results show a satisfactory performance of the platform regarding its utility. In general, users found the information useful, accurate and objective, scoring on average 4.0, 3.8 and 3.8, respectively. Additionally, and more importantly, users considered that the platform assisted them in the decision making process on a high degree, which is extremely relevant to this research, given the fact that it gives an indication that the tool effectively provides



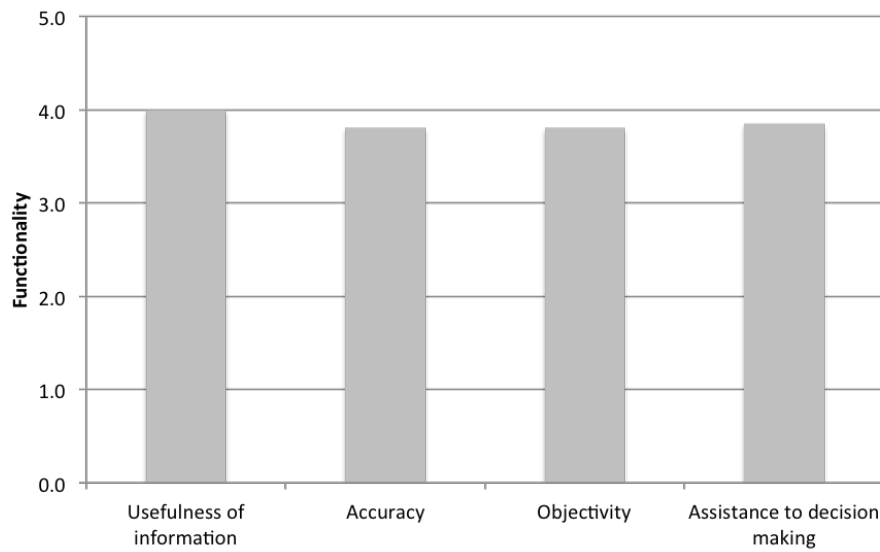


Figure 5.19: Results: Platform Functionality

strategies for problem solving, which is precisely the goal intended with the development of the support tool specifically and the overall method in general.

However, it is important to consider that, being this a relative evaluation, and that no comparative observations were made, the evaluation results can not be fully considered as conclusive. As a matter of fact, it is important to evaluate the possibility of making a comparative study for the work ahead.

## Chapter 6

# Conclusions and further research

### 6.1 Conclusions

A number of interesting conclusions, specifically associated with the impact of heuristics in the concept generation processes, emerged from the validation process.

First, it becomes evident that the method not only helps designers understand in depth the problem they are approaching, but also to do so in a quicker manner. This means that the tools devoted to problem definition and functional analysis help make the initial stages of the concept generation process easier to perform due to the clarification of the pathway to follow for problem definition and structuring.

Under the premise of an existing problem at hand that is required to be solved, heuristic tools encourage designers to spend more time during concept generation activities, as it was seen during the first validation exercise. This accounts primarily for the level of detailing reached when using the methods and tools provided here. In fact, the level of complexity and detailing of the concepts reached by the participants during the brief design exercises was clearly higher when a heuristic approach was implemented than when the designers followed a traditional approach.

This fact, in association with the overall results related to time performance of the teams that used heuristics, provides a very interesting conclusion of the present research, because it can give an idea of how the overall design process can be made more effective in future stages thanks to the greater detailing obtained in initial steps of the process. This means not only that less time must be consumed in detailing solutions in later stages of the process, but also

that higher quality input will be provided to the detailing phases thanks to the higher level of development reached in said concepts at an architectural definition stage, which regularly comes earlier in the design activity. Ultimately, this means that the design process can be performed in a more resource-effective manner.

As a matter of fact, not only the level of detailing improves with the proposed approach. The overall quality of the concepts seems to present improvements, especially in the areas of usefulness and feasibility, as it was seen during the second validation exercise. This can be attributed to the fact that the method demands to fully understand the creative process from a functional perspective and to solve practical problems detected during problem formalization stages. It can also be related to the fact that the interpretation of existing solutions from diverse areas of knowledge can lead to the generation of more feasible solutions, considering that a wide range of existing technologies and solution principles can be easily explored and evaluated when conceptualizing.

Judging by the participants' response to the implementation of the heuristic approach to design tasks and particularly on the feedback provided regarding the usage of the tool, it is possible to say that the scope and reach of the tool is remarkably wide. This means that both the methodological approach and the support tools developed during this research can be of use for design practitioners regardless of their specific backgrounds, thanks to the generality and ease of understanding of the heuristic rules provided and the broad spectrum of applications shown in the tools.

On the other hand, regarding the perception of the support tool that has been specially devised for this research, the results show that it has accomplished its purpose, being not only intuitive and clear, but also effective in providing information that can be useful for concept generation activities.

In fact, during the study, a particular advantage of the implementation of heuristics became apparent: lateral thinking processes started happening in the ideation stages, meaning that designers did not limit themselves to thinking within the functional domain of their design problem; some of the ideas came from functional applications in completely different domains such as architecture and biology. Furthermore designers did not limit themselves to the generation of concepts within the functional spectrum of the proposed rules. Instead, the rules often triggered ideas not directly related to the functional principles explained, but

somehow connected to them. This opened the opportunity for more diverse concepts.

## 6.2 Future work

Firstly, it is important to note that the statistical validity of the present study is limited, having performed two different validation exercises with a total of 18 participants divided in 6 groups for the first exercise and 31 individuals for the second; therefore it is recommended to continue with the validation process until a higher statistical relevance is reached.

Additionally, the current validation process has covered the execution of a design task in a limited scope: beginning from the problem definition to the general architectural structuring of a solution and a preliminary concept generation stage. However, it is important to assess what kind of input can be provided to the remaining steps of the process through the incorporation of heuristics into conceptualization, detailed design and materialization. Furthermore, it is crucial to evaluate the overall design process from conception to materialization, in order to fully understand the effects of heuristics in design.

In hand with the previous observation, it is important to note that given that the present work is focused on providing the designer with a set of possible solution principles for diverse design problems, the designer must approach the method with an existing problem at hand. This must be done in order to fully exploit the potential of the tools explored here and to be able to identify the action to be taken over said problem. This proposes an interesting area for future exploration, meaning that the approach must be tested in a context where no previous reference exists and assess the impact that the method might have under such circumstances.

It is also necessary to approach the dilemma that designers face when having to decide which branch to follow towards the resolution of the design problem. This, in principle, is mostly a matter of expertise, familiarity with the method and intuition. However, given that these three factors are highly dependent on an individual's background, it is important to evaluate how to guide designers effectively through the decision-making process associated with the selection of particular heuristic rules, and provide them with the appropriate rules for the specific problems being explored. This will help solve the issue of selecting rules repetitively and might help in the diversification of concepts.

On the other hand, although the process for the capitalization of knowledge has been out-

lined, the scope of the present research does not cover the validation of said aspect. Therefore, it is recommended to perform further validation exercises focused on how to effectively capture emerging knowledge from new design activities.

The current research has been carried out within an academic environment, giving positive results. However, the applicability of the complete proposed method in industrial environments is yet to be determined. Nevertheless, the fact that the formulation of the heuristics contained in this study has been largely based on work carried out by Nadeau [Pailhès et al., 2007] [Pailhès et al., 2011] in collaboration with industries should serve as a preliminary indicator of its validity. In this sense, it is interesting to provide information and feedback related to the usage of the tool in industrial applications. Furthermore, the implementation of a software development for the exploration of the heuristics tree has proven to be of interest during academic exercises and its impact can be maximized if prepared and adapted for commercial applications. In this sense, it can be an interesting area of further development to enhance the website's construction, in order to make it possible to make it applicable for a commercial environment.

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## Appendix A

### Appendix A: Heuristic cards

This appendix compiles some of the heuristic cards that were used in the validation process contained in this document.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally  
► Through the segmentation of components ► Through the division into independent, removable, adjustable or modular components



Modular  
Design

"Xi3 modular computer 01" by <http://www.flickr.com/people/mbtrama/> - <http://www.flickr.com/photos/mbtrama/5353387071/>.  
Licensed under Creative Commons Attribution 2.0  
via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Xi3\\_modular\\_computer\\_01.jpg#mediaviewer/File:Xi3\\_modular\\_computer\\_01.jpg](http://commons.wikimedia.org/wiki/File:Xi3_modular_computer_01.jpg#mediaviewer/File:Xi3_modular_computer_01.jpg)



Modular  
Furniture



Honeycomb

"Bee on his alvear" by Giuliagi - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Bee\\_on\\_his\\_alvear.jpg#mediaviewer/File:Bee\\_on\\_his\\_alvear.jpg](http://commons.wikimedia.org/wiki/File:Bee_on_his_alvear.jpg#mediaviewer/File:Bee_on_his_alvear.jpg)



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally  
► Through the segmentation of components ► Through the division into independent, removable, adjustable or modular components

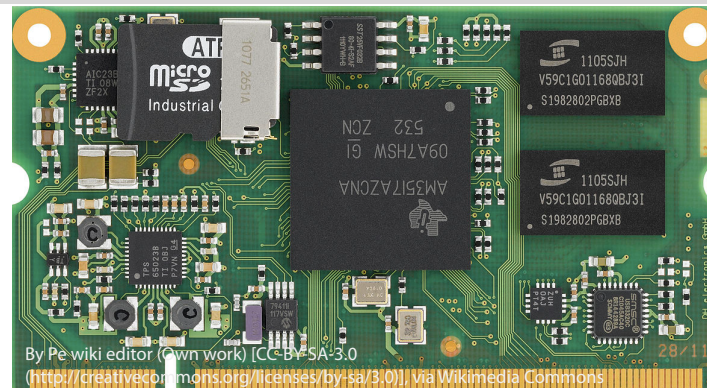


By Asa Wilson (CubeSpace) [CC-BY-SA-2.0 (<http://creativecommons.org/licenses/by-sa/2.0>)], via Wikimedia Commons

Modular furniture is defined as furniture made up of independent work surfaces, volumes and storage units, built with standard units and components, which makes it easily configurable.

It is often pre-made or ready made furniture which can be used according to the need and room spacing.

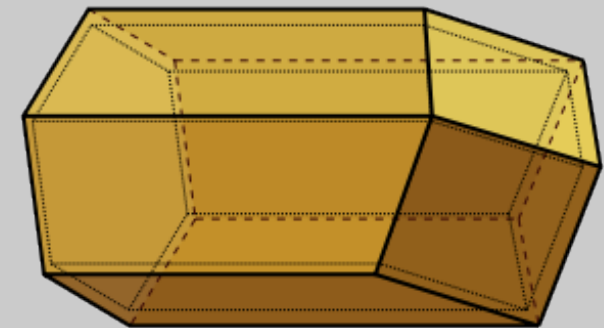
The purpose of modular furniture is for it to be separable, interchangeable and flexible, making it possible to adjust the design according to space or usability requirements.



Modular design, or "modularity in design", is an approach that subdivides a system into smaller parts (modules or skids) that can be independently created and then used in different systems to drive multiple functionalities. A modular system can be characterized by the following:

- (1) Functional partitioning into discrete scalable, reusable modules consisting of isolated, self-contained functional elements.
- (2) Rigorous use of well-defined modular interfaces, including object-oriented descriptions of module functionality
- (3) Ease of change to achieve technology transparency and, to the extent possible, make use of industry standards for key interfaces

A computer is actually one of the best examples of modular design - typical modules are power supply units, processors, mainboards, graphics cards, hard drives, optical drives, etc. All of these parts should be easily interchangeable as long as you use parts that support the same standard interface as the part you replaced.



By User:Iseeaboar [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0>)], via Wikimedia Commons

The axes of honeycomb cells are always quasi-horizontal, and the nonangled rows of honeycomb cells are always horizontally aligned. Thus, each cell has two vertical walls, with "floors" and "ceilings" composed of two angled walls. The cells slope slightly upwards, towards the open ends.

There are two possible explanations for the reason that honeycomb is composed of hexagons, rather than any other shape. One is that the hexagon tiles the plane with minimal surface area. Thus, a hexagonal structure uses the least material to create a lattice of cells within a given volume. Another is that the shape simply results from the process of individual bees putting cells together: somewhat analogous to the boundary shapes created in a field of soap bubbles. In fact, queen cells, which are constructed singly, are irregular and lumpy with no apparent attempt at efficiency

The bees begin to build the comb from the top of each section. When a cell is filled with honey, the bees seal it with wax.

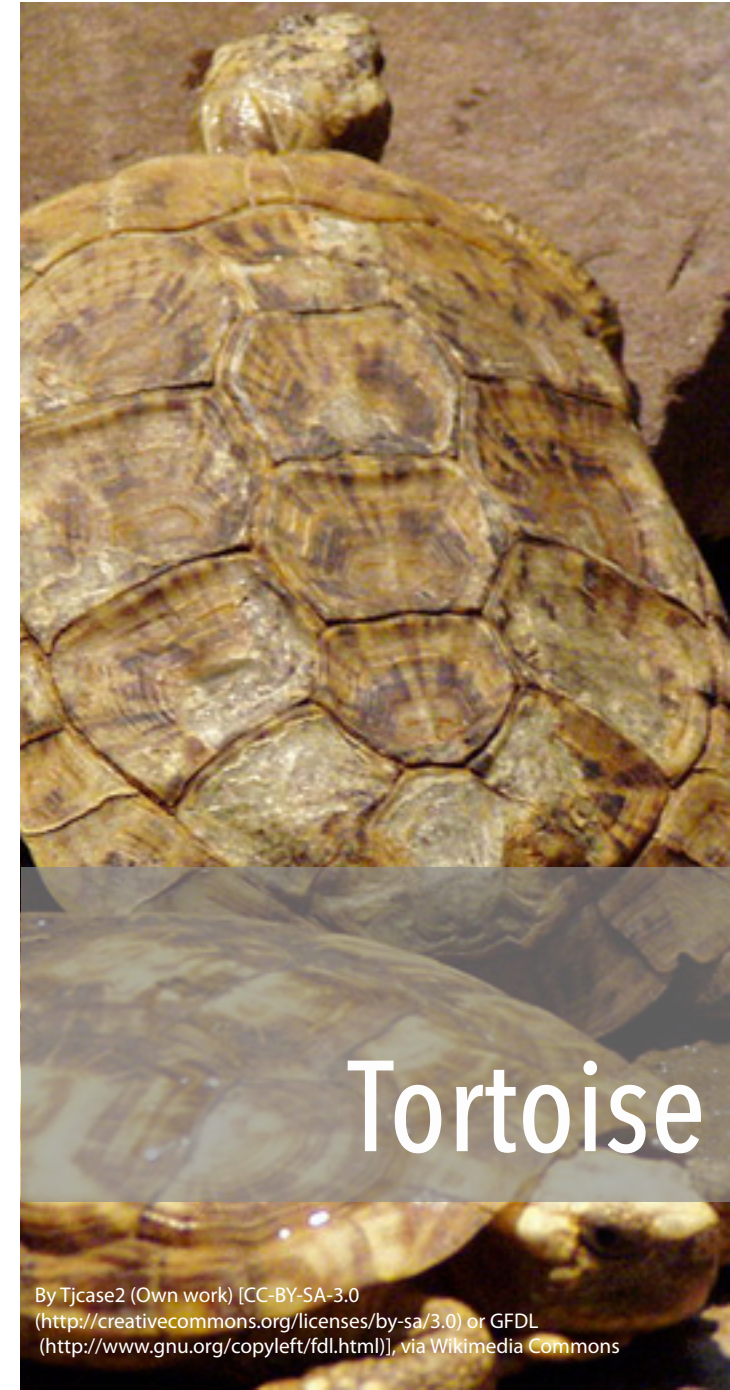
Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ►  
Through the adaptation of components ► Through the evolution of materials ► From rigid to deformable



Roller  
Chain



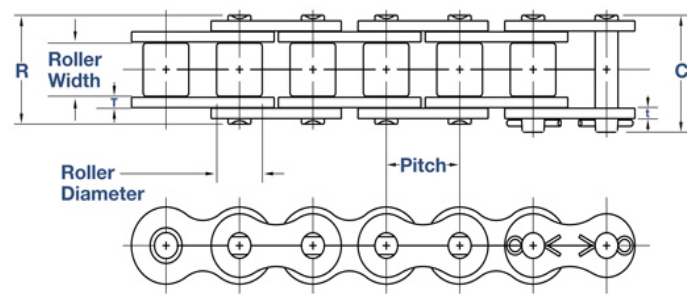
Flexible Love  
Chair



Tortoise



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of materials ► From rigid to deformable



Kaman Industrial Technologies Corp.  
[http://www.reliamark.com/images/diagrams/roller\\_chain/metric-british-chain-single-strand.jpg](http://www.reliamark.com/images/diagrams/roller_chain/metric-british-chain-single-strand.jpg)

Roller chain or bush roller chain is the type of chain drive most commonly used for transmission of mechanical power on many kinds of domestic, industrial and agricultural machinery

It consists of a series of short cylindrical rollers held together by side links.

This particular configuration makes roller chains simultaneously rigid and flexible: The segmentation of the chain into a specific number of links makes it rigid at a local level (where each of the links is placed), but flexible at a global level, when all the individual links are added up.



Most terrestrial tortoise species have firm, dense shells. However, the pancake tortoise has shell bones with many openings, making it lighter and more agile than other tortoises.

Furthermore, this particularity makes the shell, which is often a tough defense, somewhat flexible at a local scale. Where the bones are hollow or have open spaces, the shell becomes softer and more flexible.

This is a great survival advantage for the tortoises, since it allows for these animals to wedge into crevices to escape predation.



This chair is constructed almost entirely from recycled cardboard and recycled wood waste and can expand to hold up to 16 people.

At first glance, the design of the FlexibleLove chair seems quite simple, but once you see how quickly and easily it can be expanded and contracted, you really appreciate the complexity of its design. The unique qualities of its accordion and honeycomb structure allow it to be stretched and folded into a multitude of shapes and lengths - creating surprisingly strong seating. To change its length and shape, you simply pull each end – much like playing an accordion.

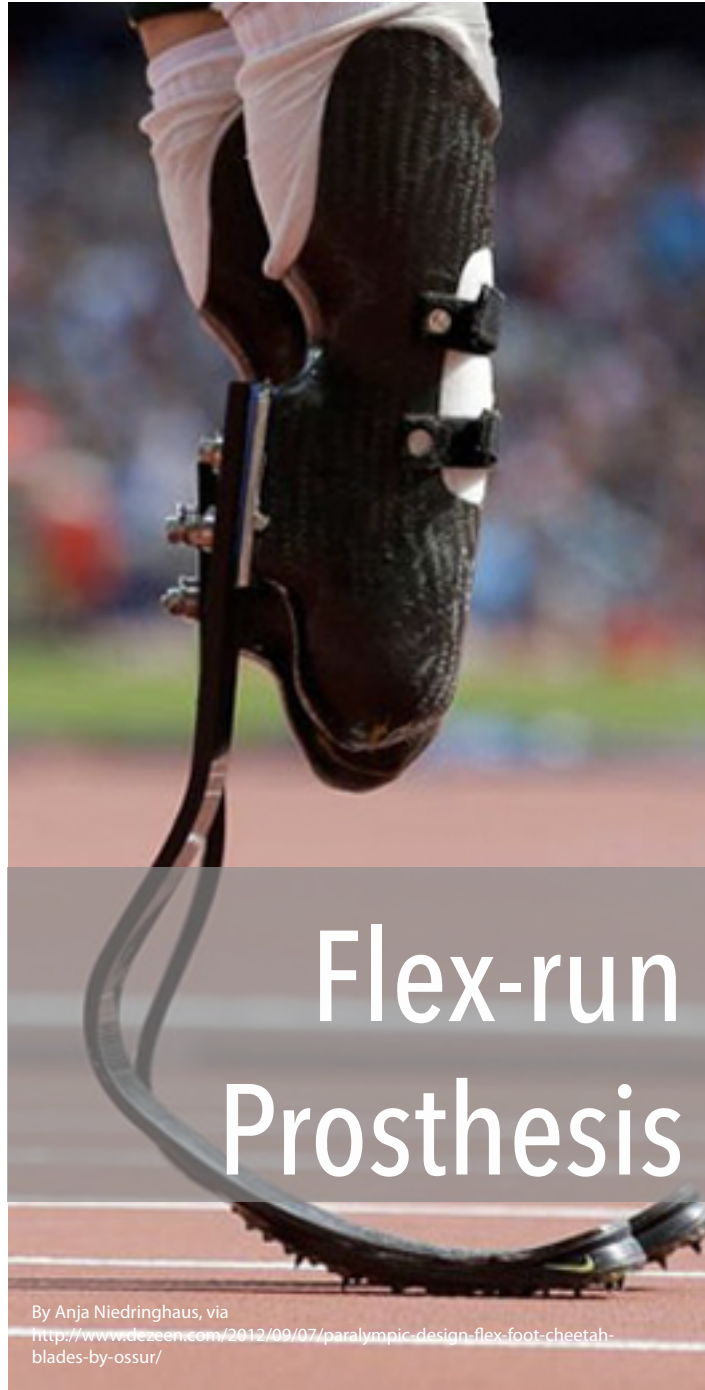
The body weight is divided evenly between the hundreds of cells contained in the chair.

Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Through the adaptation of the components > Through the evolution of the shape > Adapted to the materials > According to mechanical stress



Arch

By St\_Louis\_night\_explend.jpg: Daniel Schwen derivative work: fetchcomms (St\_Louis\_night\_explend.jpg) [CC-BY-SA-2.5] (<http://creativecommons.org/licenses/by-sa/2.5>), CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)), via Wikimedia Commons



Flex-run  
Prosthesis

By Anja Niedringhaus, via <http://www.dezeen.com/2012/09/07/paralympic-design-flex-foot-cheetah-blades-by-ossur/>

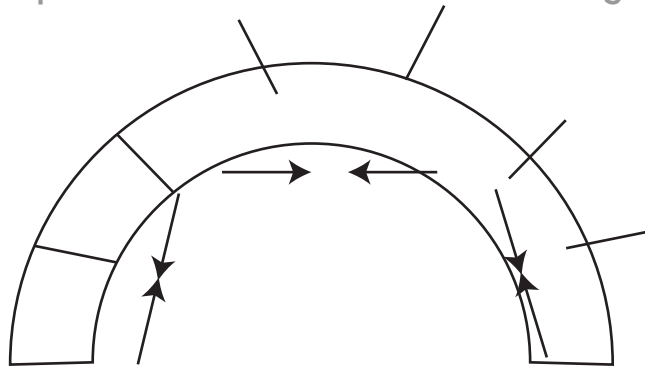


Sea  
Urchin

By Steve Jurvetson from Menlo Park, USA (Sunken Treasure Uploaded by Huntster) [CC-BY-2.0 (<http://creativecommons.org/licenses/by/2.0>)], via Wikimedia Commons



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Through the adaptation of the components > Through the evolution of the shape > Adapted to the materials > According to mechanical stress



An arch is a structure that spans a space and supports structure and weight below it.

An arch is a pure compression form. It can span a large area by resolving forces into compressive stresses and, in turn eliminating tensile stresses. This is sometimes referred to as arch action. As the forces in the arch are carried to the ground, the arch will push outward at the base, called thrust.

As the rise, or height of the arch decreases, the outward thrust increases. In order to maintain arch action and prevent the arch from collapsing, the thrust needs to be restrained, either with internal ties, or external bracing, such as abutments.



The Flex-Foot Cheetah and similar models are worn by Oscar Pistorius and other amputee athletes in the Paralympics and elsewhere. It is made from carbon fibre, and unlike all previous foot prostheses,[citation needed] it stores kinetic energy from the wearer's steps as potential energy, like a spring, allowing the wearer to run and jump.

Carbon fiber is actually a carbon-fiber-reinforced polymer, and is a strong, lightweight material used in a number of applications, including sporting goods like baseball bats, car parts, helmets, sailboats, bicycles and other equipment where rigidity and high strength-to-weight ratio is important. The polymer used for this equipment is normally epoxy, but other polymers are also used, depending on the application, and other reinforcing fibers may also be included. In the blade manufacturing process, sheets of impregnated material are cut into square sheets and pressed onto a form to produce the final shape.



Shell of a sea urchin. By DMF Prazeres. [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0) Via Asknature.org]

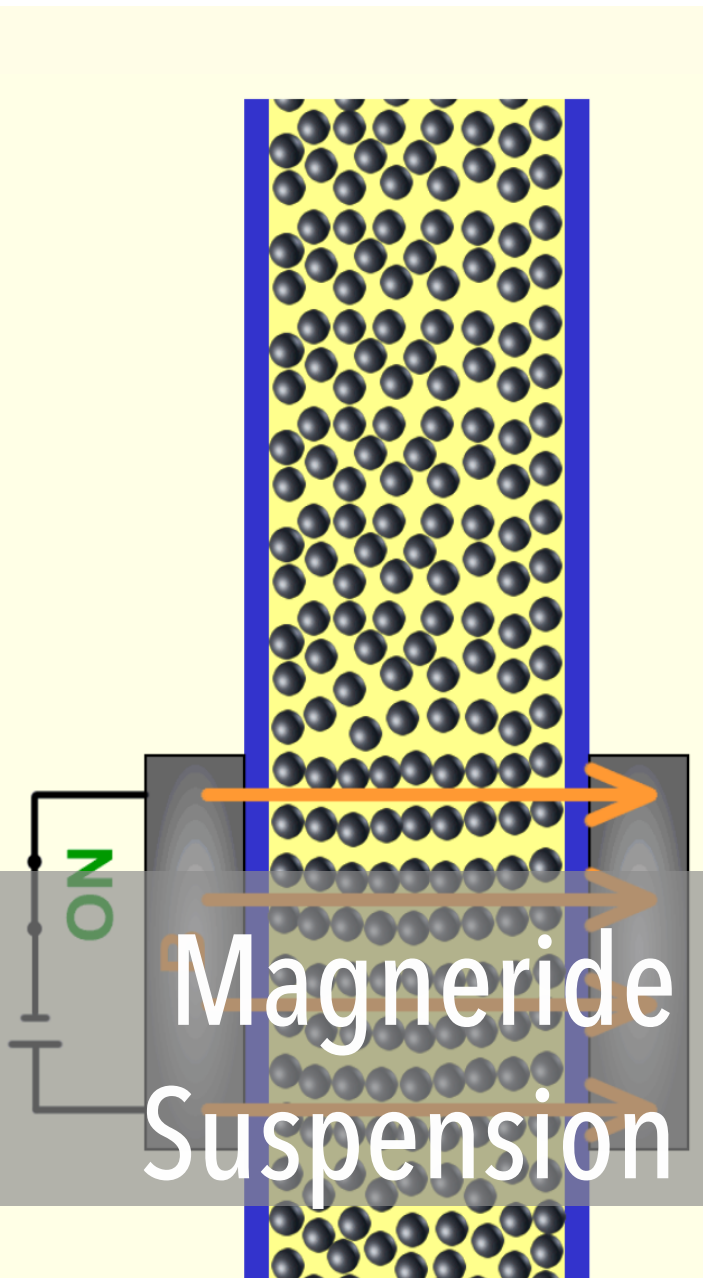
Spheres, like many other geometric shapes, are distorted by gravity. If a drop of liquid, held together by surface tension, is placed on a surface and therefore subjected to the force of gravity, it tends to become a more flattened shape, called 'oblate'.

The shell of a sea urchin, stripped of its spines, is oblate. This shape distributes stress evenly over the surface and therefore reduces the likelihood of cracking or breaking.

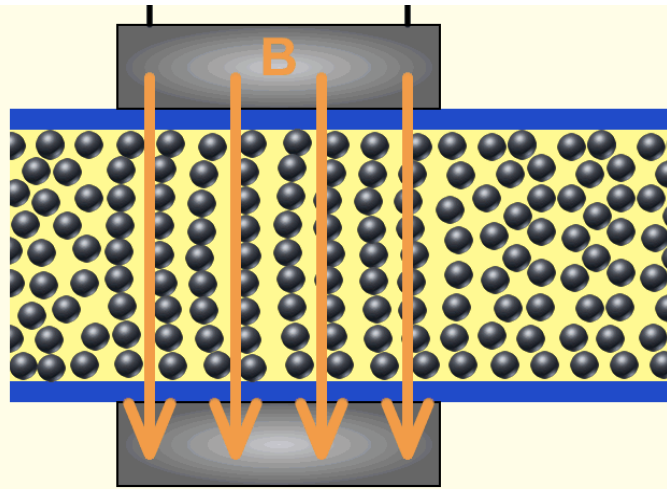
The guiding principle of economy is always apparent: a shape is most efficient when it reduces its work to a minimum.



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system Through the adaptation of the components > Through the evolution of the flow> Following the MATHEM logic of field evolution > Through the replacement or superposition of a mechanical flow for another mechanical flow (thermal, optical, chemical)



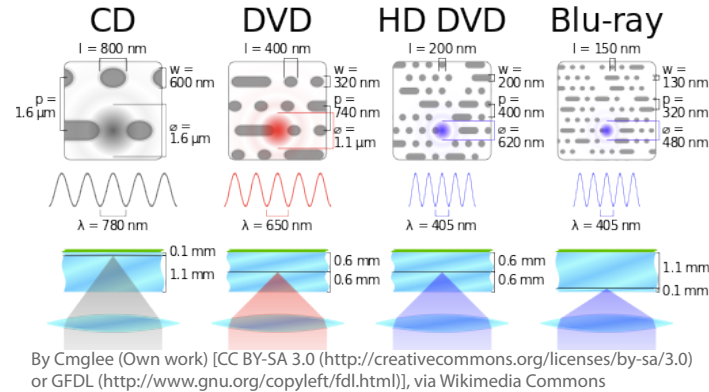
Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system Through the adaptation of the components > Through the evolution of the flow> Following the MATHEM logic of field evolution > Through the replacement or superposition of a mechanical flow for another mechanical flow (thermal, optical, chemical)



By INVENTUS Engineering GmbH (Wikimedia commons) [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

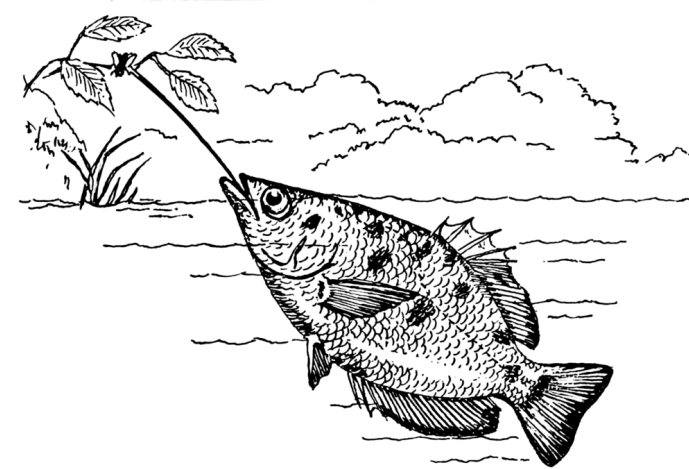
MagneRide is an automotive adaptive suspension with Magnetorheological damper system.

The dampers are filled with magnetorheological fluid, a mixture of easily magnetized iron particles in a synthetic hydrocarbon oil. In each of the monotube dampers is a piston containing two electromagnetic coils and two small fluid passages through the piston. The electromagnets are able to create a variable magnetic field across the fluid passages. When the magnets are off, the fluid travels through the passages freely. However, when the magnets are turned on, the iron particles in the fluid create a fibrous structure through the passages in the same direction of the magnetic field. The strength of the bonds between the magnetized iron particles causes the viscosity of the fluid to increase resulting in a stiffer suspension. Altering the strength of the current results in an instantaneous change in force of the piston.



Shortly after the demise of quadraphonic sound, the electronics industry moved into the digital era, and particularly optical recording. Following the pioneering work of Philips on an optical video player in the early 70's, a project was started in 1974 within Philips and its Research laboratories to develop a digital optical audio disk with error correction code. Parallel work on digital optical audio recording was done in a number of companies and Sony first publicly demonstrated an optical digital audio disc at the 1977 Audio Fair. On 8 March 1979, Philips demonstrated for the international press a 11.5 cm Optical Disk and a Compact Disc Audio Player. The demonstration showed that it is possible by using digital optical recording and playback to reproduce audio signals with superb stereo quality, as opposed to the mechanical means used before.

<http://www.research.philips.com/technologies/projects/cd/>

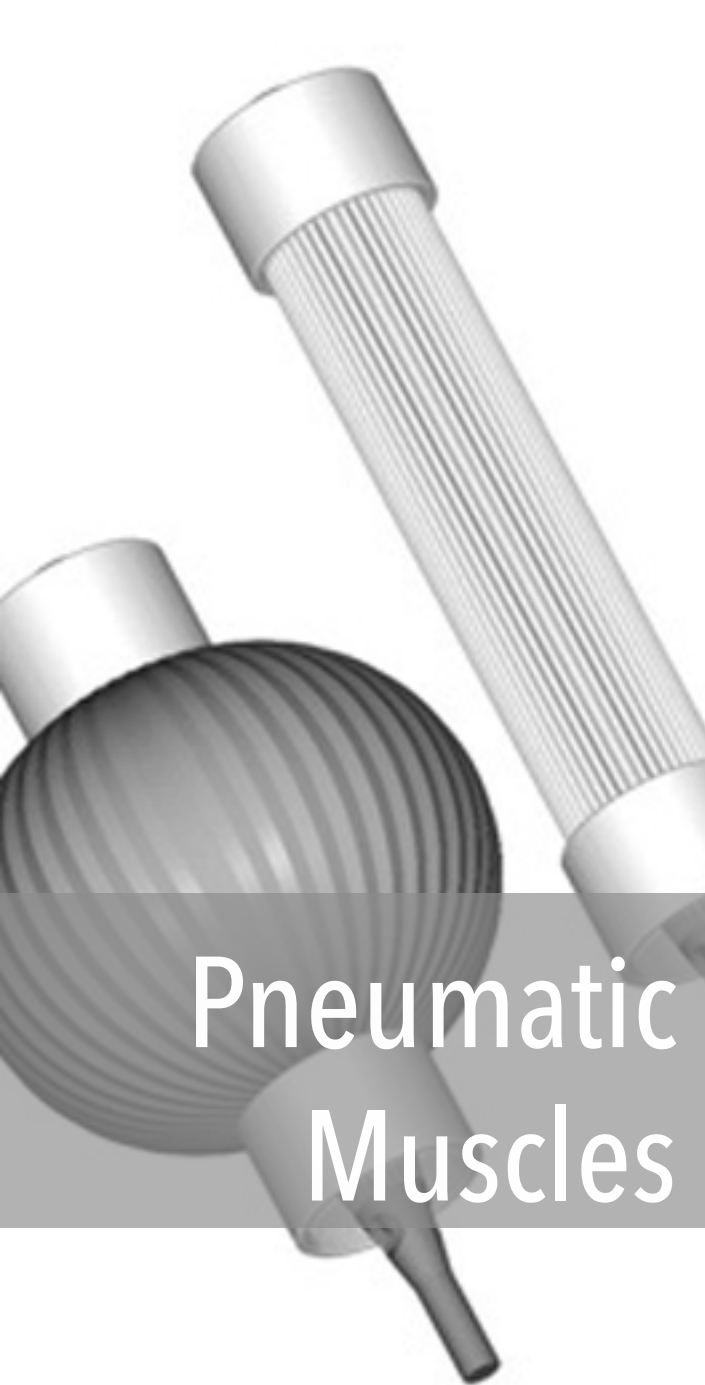


Archerfish have developed a unique hunting technique: knocking land insects down with a water stream. This extraordinary “mechanical” skill gives them a great advantage when foraging.

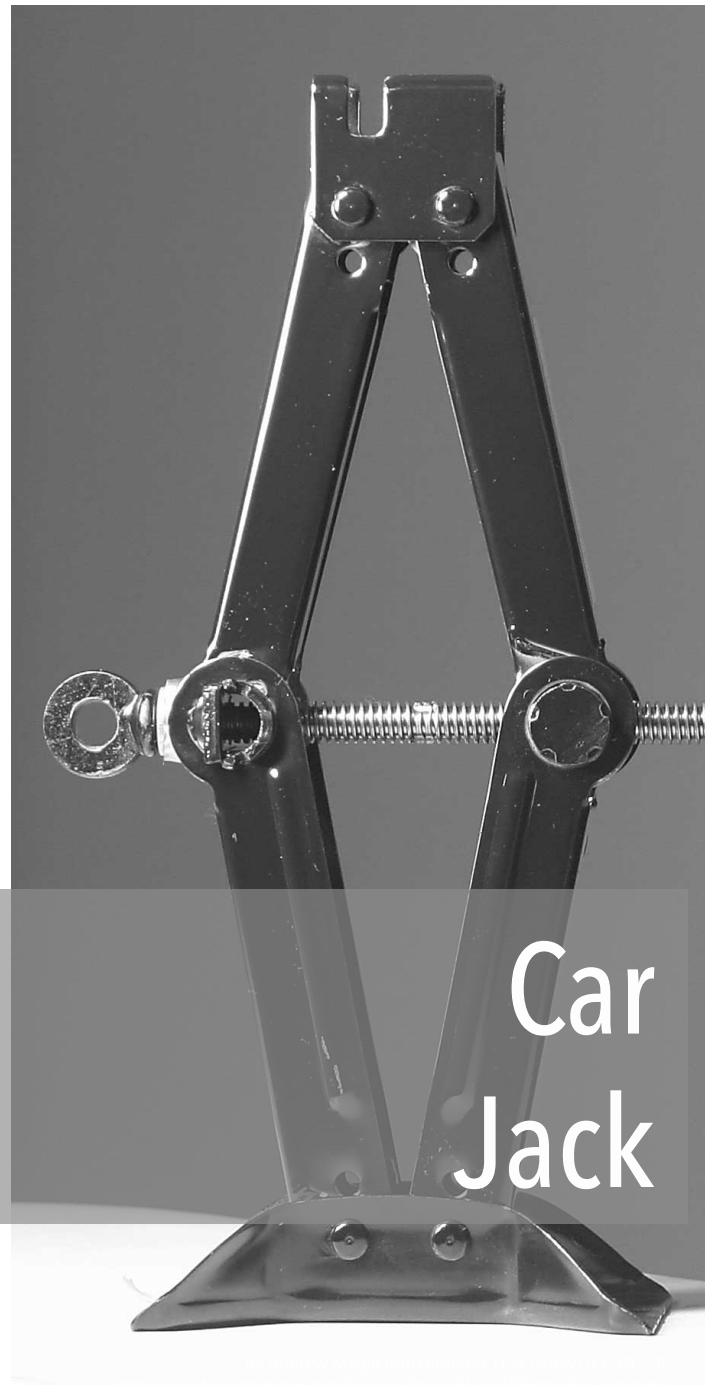
Archerfish are remarkably accurate in their shooting; adult fish almost always hit the target on the first shot. They can bring down insects and other prey up to 3 m above the water's surface. This is partially due to their good eyesight, but also their ability to compensate for the refraction of light as it passes through the air-water interface when aiming for their prey. They typically spit at prey at a mean angle of about 74° from the horizontal, but can still aim accurately when spitting at angles between 45 and 110°.



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Modifying components > Globally > Segmenting the flow > By passing from a deformable system to a rigid system through the modification of the behaviour of the components (flexion to traction+compression -trusses- and traction and compression.



Pneumatic  
Muscles



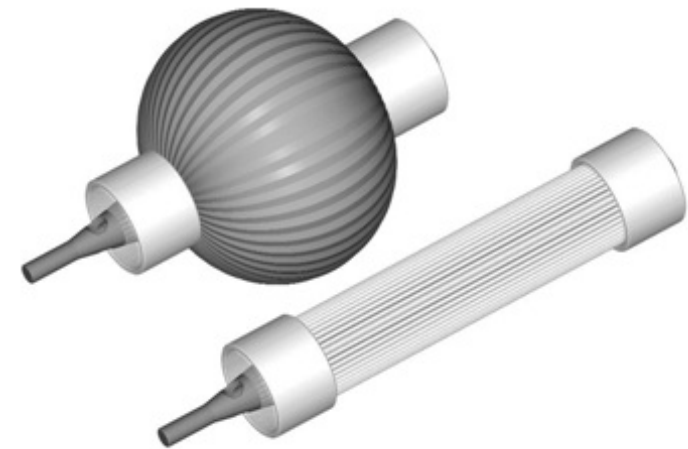
Car  
Jack



Elephant's  
Trunk

By Just chaos (Flickr) [CC-BY-2.0 (<http://creativecommons.org/licenses/by/2.0/>) via Wikimedia Commons]

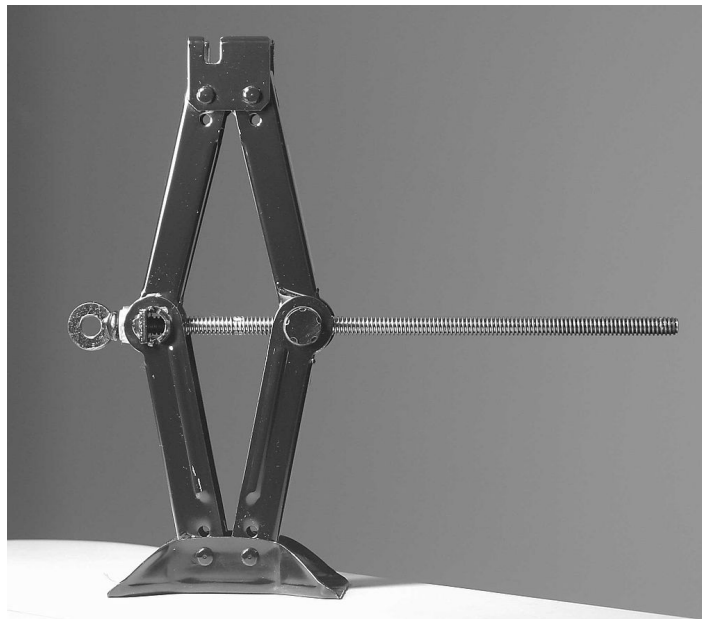
Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Modifying components > Globally > Segmenting the flow > By passing from a deformable system to a rigid system through the modification of the behaviour of the components (flexion to traction+compression -trusses- and traction and compression.



Pneumatic artificial muscles (PAMs) are contractile and/or extensional devices operated by pressurized air filling a pneumatic bladder. In a vague approximation of human muscles, PAMs are usually grouped in pairs: one agonist and one antagonist.

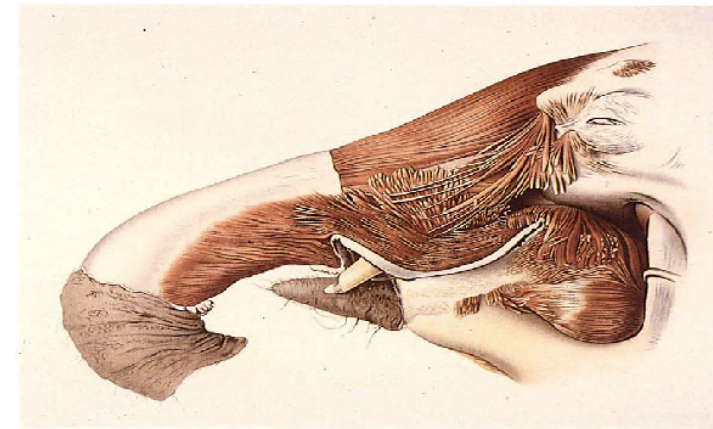
The retraction strength of the PAM is limited by the sum total strength of individual fibers in the woven shell. The exertion distance is limited by the tightness of the weave; a very loose weave allows greater bulging, which further twists individual fibers in the weave.

In PAMs the force is not only dependent on pressure but also on their state of inflation. The mathematical model that supports the PAMs functionality is a non-linear system. The relationship between force and extension in PAMs mirrors what is seen in the length-tension relationship in biological muscle systems.



There are two main kinds of car jack: those operated by screw and those operated by hydraulics. For standard road vehicles, the screw type is most common, often coming in the form of a scissor jack. Their popularity is a result of their ability to generate a great mechanical advantage – ie a large force amplification – from a manually operated arm tool.

These jacks work by using a two-piece mechanism – similar to those found on extending bathroom mirrors – in partnership with a self-locking central screw. Combined, these elements not only enable a vehicle to be lifted through the extension of the scissor mechanism, but also to be held in place by the resistive force of the screw, which without the jack would instantly collapse.



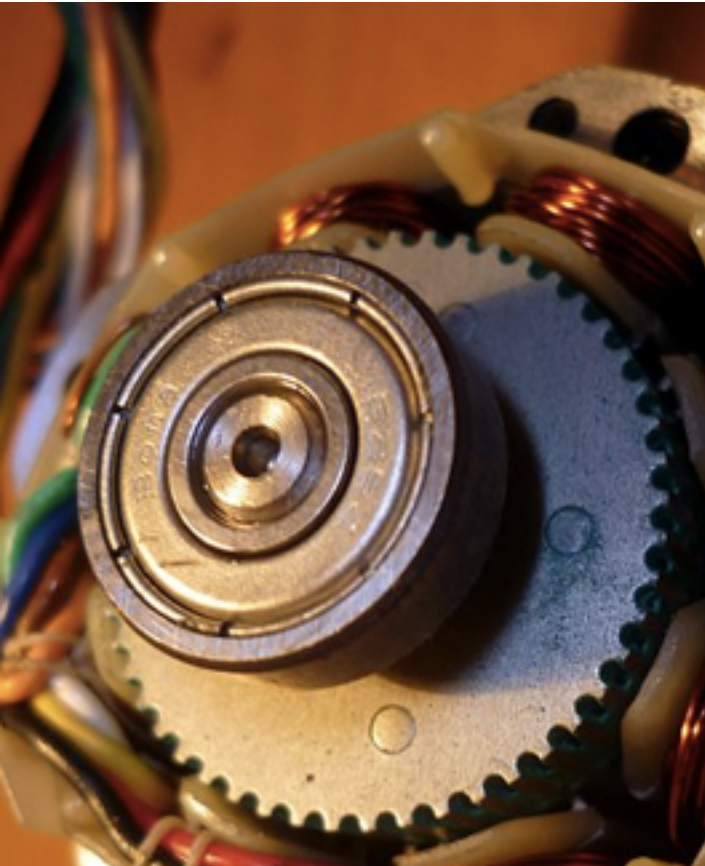
Antagonistic movement controls the movement of most muscles; meaning that while one muscle group contracts an opposing muscle group elongates thus providing a bending movement. What is unique about the trunk of an elephant, however, is that there is no skeletal structure present in its trunk to create antagonistic muscles.

Agonist and antagonist muscles work as traction/compression system, to provide the flexibility to the elephant trunk.

The trunk is made up of tightly packed muscle fibers that maintain volume to remain constant through a variety of movements. Structures composed of this incompressible fluid are known as muscular hydrostats. These muscles are arranged in three patterns (perpendicular to the long axis of the organ, parallel to the long axis, or wrapped helically, or obliquely, around the long axis) and provide versatility to the movement of the trunk.



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Through the adaptation of the components > Through the evolution of the flow > Through the coordination of rhythms > Through the transformation of a continuous action into a periodical action (or viceversa)



Stepper  
Motor

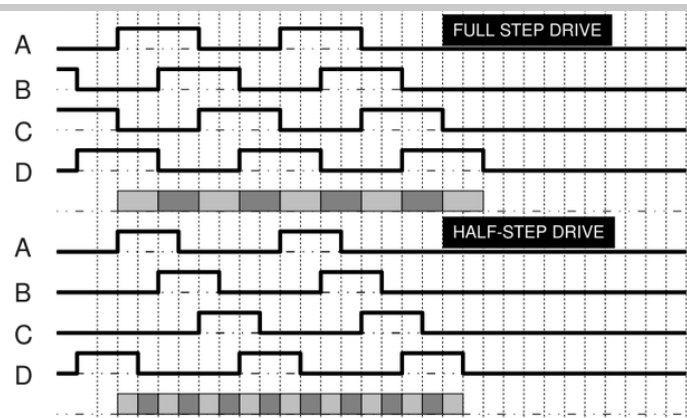


Strobe  
Lamp



Black  
Bear

Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Through the adaptation of the components > Through the evolution of the flow > Through the coordination of rhythms > Through the transformation of a continuous action into a periodical action (or viceversa)



By Misan2010 (Own work) [CC BY 3.0 (<http://creativecommons.org/licenses/by/3.0/>)], via Wikimedia Commons

A stepper motor is a brushless DC electric motor that divides a full rotation into a number of equal steps.

The stepper motor converts a train of input pulses into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle. Stepper motors effectively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control circuit, such as a microcontroller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next one. This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one. From there the process is repeated. Each of those rotations is called a "step". In that way, the motor can be turned by a precise angle.



A strobe light is a device used to produce regular flashes of light

Strobe lights usually use flashtubes with energy supplied from a capacitor, an energy storage device much like a battery, but capable of charging and releasing energy much faster. The capacitor is charged up to around 300V. Once the capacitor has been charged, a small amount of power is diverted into a trigger transformer, a small transformer with a high turns ratio, which generates a weak, but high voltage spike required to ionize the xenon gas in a flash tube. An arc is created inside the tube, which acts as a bridge for the much bigger pulse to flow down later. Arcs present almost a direct short circuit, allowing the capacitors to quickly release their energy into the arc. This rapidly heats the xenon gas, creating an extremely bright plasma discharge, which is seen as a flash.



Hibernation is continuous dormancy with distinct decreases in heart rate and metabolic rate. Bears use up to 4,000 kcal per day, mainly body fat, but do not eat, drink, urinate, or defecate. They can reduce oxygen consumption and metabolic rate by half and breathe only once every 45 seconds. Heart rate can drop periodically to 8-21 beats per minute, and blood flow to skeletal muscle, particularly the legs, can be reduced by 45% or more, making some bears slow to arouse and run away in winter. Blood perfusion rates of peripheral tissues can fall below levels needed for aerobic metabolism in humans.

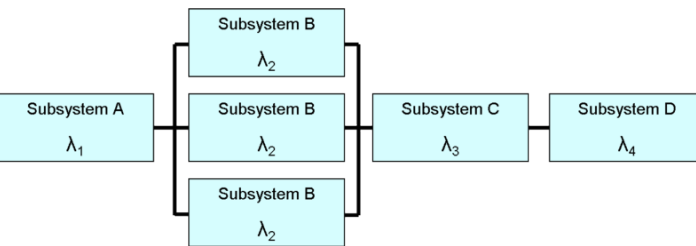


Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the components > Into different components with identical functions.





Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the components > Into different components with identical functions.



In engineering, redundancy is the duplication of critical components or functions of a system with the intention of increasing reliability of the system, usually in the form of a backup or fail-safe.

In many safety-critical systems, such as fly-by-wire and hydraulic systems in aircraft, some parts of the control system may be triplicated, which is formally termed triple modular redundancy (TMR). An error in one component may then be out-voted by the other two. In a triply redundant system, the system has three sub components, all three of which must fail before the system fails. Since each one rarely fails, and the sub components are expected to fail independently, the probability of all three failing is calculated to be extraordinarily small; often outweighed by other risk factors, e.g., human error.

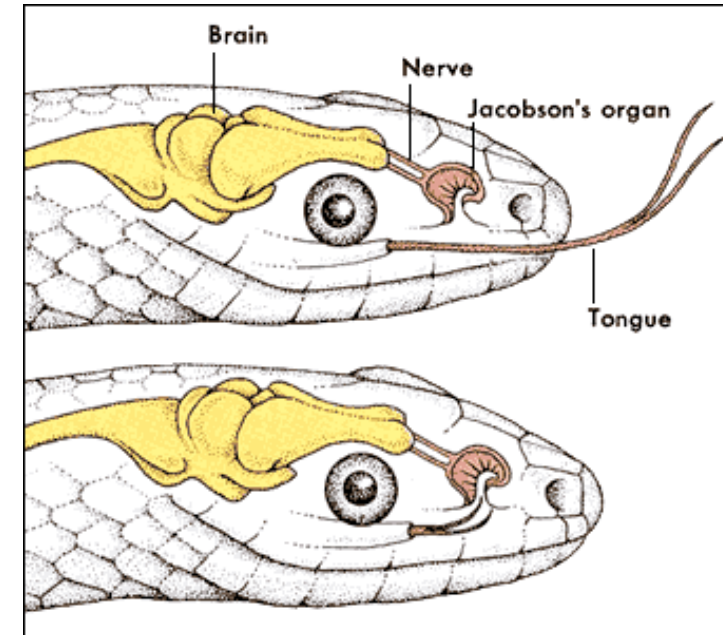


By Kansai explorer (Own work) [GFDL (<http://www.gnu.org/copyleft/fdl.html>) or CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

Most Eco-Drive type watches are equipped with a special titanium lithium ion secondary battery charged by an amorphous silicon photocell located behind the dial. Light passes through the crystal and dial before reaching the photocell.

Depending on the electronic movement, a fully charged secondary power cell could run with no further charging from 30 days to 3,175 days (8.7 years), though most Eco-Drive men's watch models offer a six-month power reserve.

Citizen also built an automatic quartz powered watch, the Citizen Promaster Eco-Duo Drive (released in December 1998). Novel to this watch was the use of both mechanical power as well as a solar cell to power the electronic movement and charge the secondary power cell.



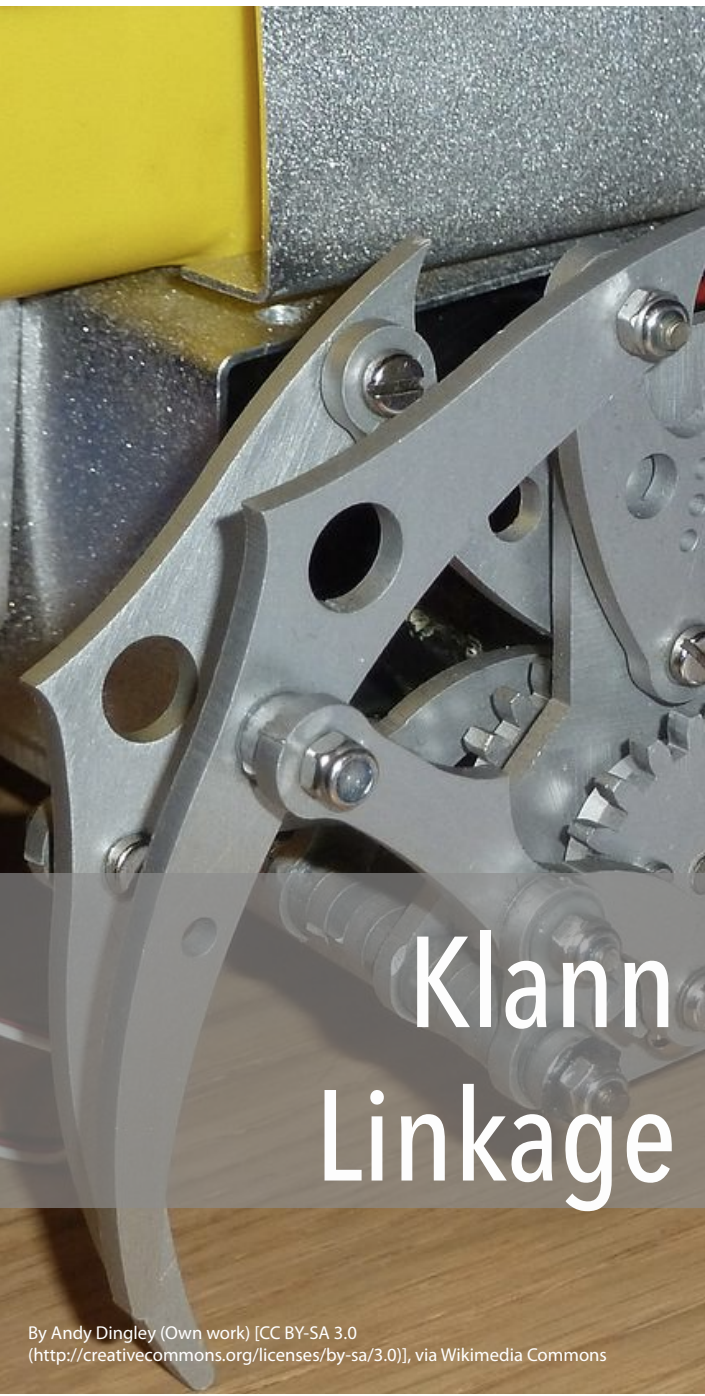
Most snakes have an excellent sense of smell, in part to make up for their poor eyesight and limited hearing.

Rather than a conventional nose, however, snakes sniff with an organ at the roof of the mouth called a Jacobson's organ, which is also found in a few lizard species.

Snakes flick their tongues to collect scent particles for this organ. The prongs of the forked tongue is stuck into a pair of holes in the Jacobson's organ. The snake's nostrils also play a supporting role.



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the coordination of components > Through the coordination of rhythms > Coupling by phase, by opposing phase, by resonance or compensation



Klann  
Linkage

By Andy Dingley (Own work) [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons



Timing  
Belt

By Petar Milošević (Own work) [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

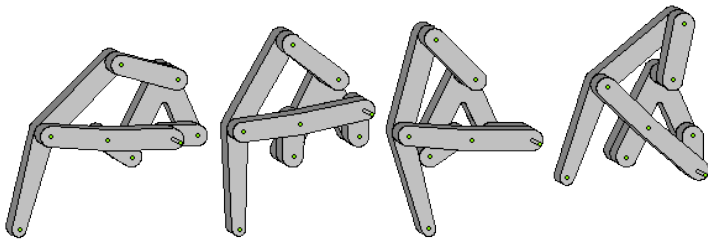


Mosquitofish

By NOZO (Own work (本人撮影)) [GFDL (<http://www.gnu.org/copyleft/fdl.html>), CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or CC BY-SA 2.5-2.0-1.0 (<http://creativecommons.org/licenses/by-sa/2.5-2.0-1.0/>)], via Wikimedia Commons

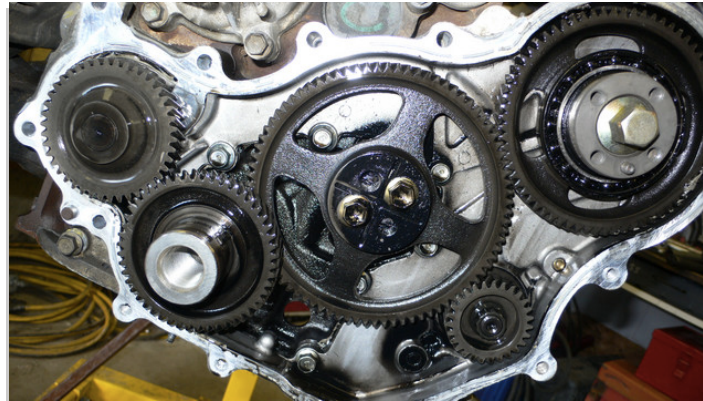


Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the coordination of components > Through the coordination of rhythms > Coupling by phase, by opposing phase, by resonance or compensation



The Klann linkage is a planar mechanism designed to simulate the gait of legged animal and function as a wheel replacement. The linkage consists of the frame, a crank, two grounded rockers, and two couplers all connected by pivot joints.

The proportions of each of the links in the mechanism are defined to optimize the linearity of the foot for one-half of the rotation of the crank. The remaining rotation of the crank allows the foot to be raised to a predetermined height before returning to the starting position and repeating the cycle. Two of these linkages coupled together at the crank and one-half cycle out of phase with each other will allow the frame of a vehicle to travel parallel to the ground.



A timing belt, timing chain or cam belt is a part of an internal combustion engine that synchronizes the rotation of the crankshaft and the camshaft(s) so that the engine's valves open and close at the proper times during each cylinder's intake and exhaust strokes. In an interference engine the timing belt or chain is also critical to preventing the piston from striking the valves. A timing belt is a belt that usually features teeth on the inside surface, while a timing chain is a roller chain.

Variable valve timing can give both maximum power at high rpm and smooth idling at low rpm by making small changes to the relative angular position of the camshafts and thereby varying the valve overlap.



Large groups of mosquitofish can move together with little physical contact between individuals. This is because the individual fish coordinate their acceleration and deceleration. The fish accelerate toward a neighbor that is far away from or behind them, and decelerate when a neighbor is directly in front of them.

This means that individual fish can interpret speed cues from other fish close to them, and therefore they are capable of coordinating their swimming rhythm in order to maintain an appropriate distance between each other.



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the components > Making them evolve from homogenous to heterogenous (or viceversa)



Cemented  
Carbide



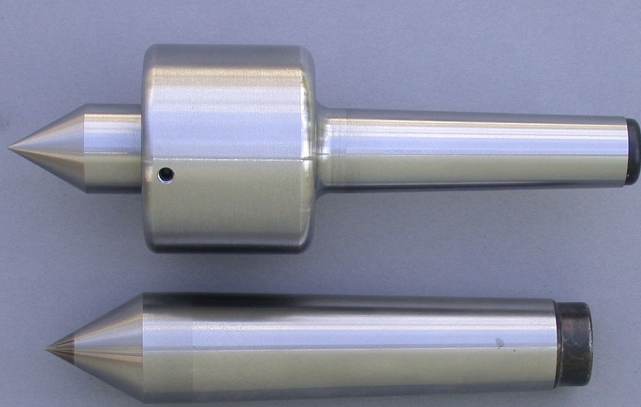
Floating Disc  
Brake



Angler  
Fish



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the components > Making them evolve from homogenous to heterogenous (or viceversa)



By Graibeard (Own work) [CC BY 2.0 (<http://creativecommons.org/licenses/by/2.0/>)], via Wikimedia Commons

Cemented carbides are composed of a metal matrix composite where carbide particles act as the aggregate and a metallic binder serves as the matrix. During the sintering process the binder eventually will be entering the liquid stage and carbide grains (much higher melting point) remain in the solid stage. As a result of this process the binder is cementing the carbide grains and thereby creates the metal matrix composite with its distinct material properties. The naturally ductile metal binder serves to offset the characteristic brittle behavior of the carbide ceramic, thus raising its toughness and durability.

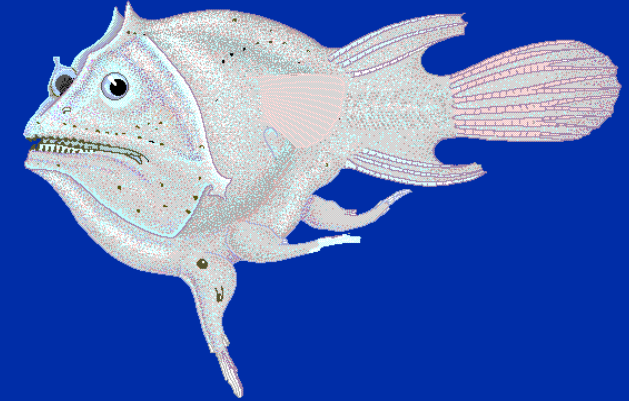
In machining applications, the carbide cutting tip itself is often in the form of a small insert for a larger tipped tool whose shank is made of another material, usually carbon tool steel.



By Christian Kunze (Own work) [GFDL (<http://www.gnu.org/copyleft/fdl.html>), CC-BY-SA-3.0(<http://creativecommons.org/licenses/by-sa/3.0/>) or CC BY-SA 2.5-2.0-1.0 (<http://creativecommons.org/licenses/by-sa/2.5-2.0-1.0/>)], via Wikimedia Commons

Floating brake discs are constructed in two parts. An aluminium centre part which is fixed to the motorcycle wheel and a stainless rotor part which the brake pads push on.

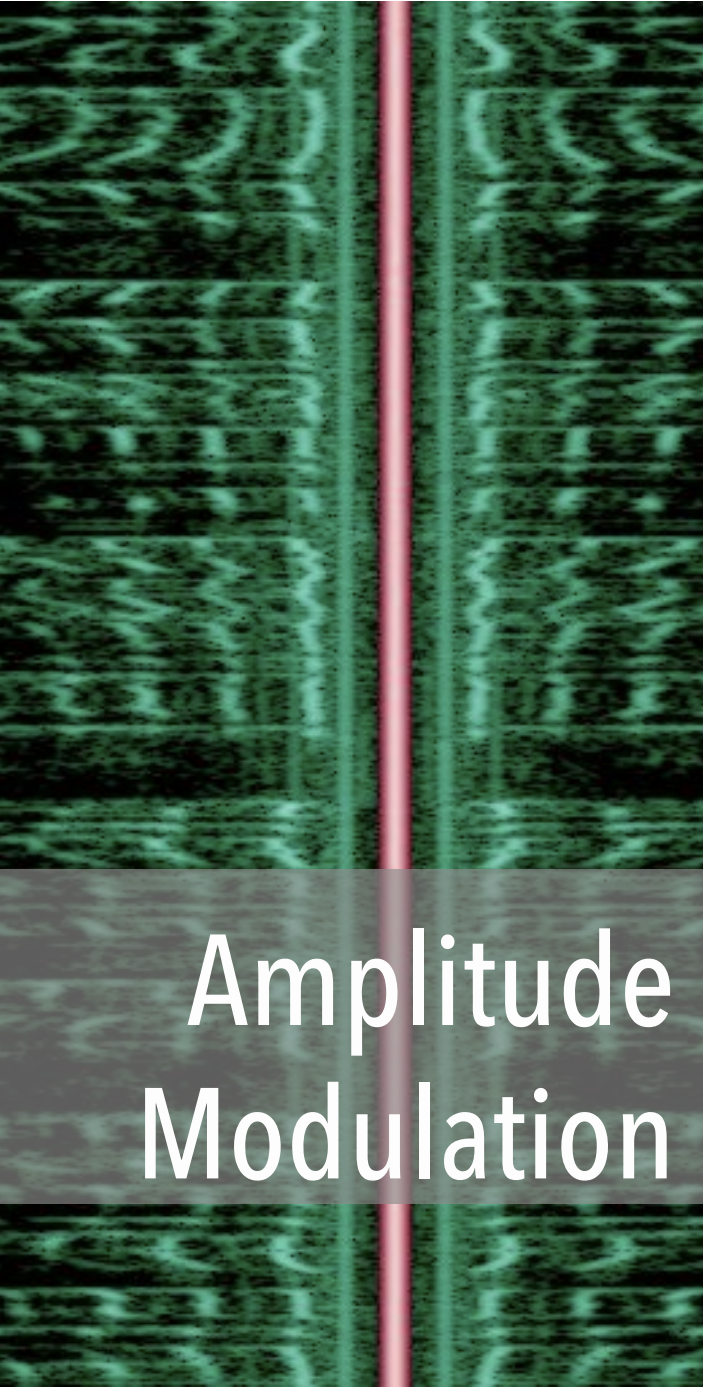
When the rotor is subjected to serious heat it expands. By allowing it to float separately from the mounting face it is free to expand and shrink again at will without being constrained by its mounting. When this expansion takes place it does so in all directions at once and it will not be constrained. If you prevent this from happening in one direction (by fixing it on its mounting face) it has no choice but to warp, so floating discs prevent them from warping.



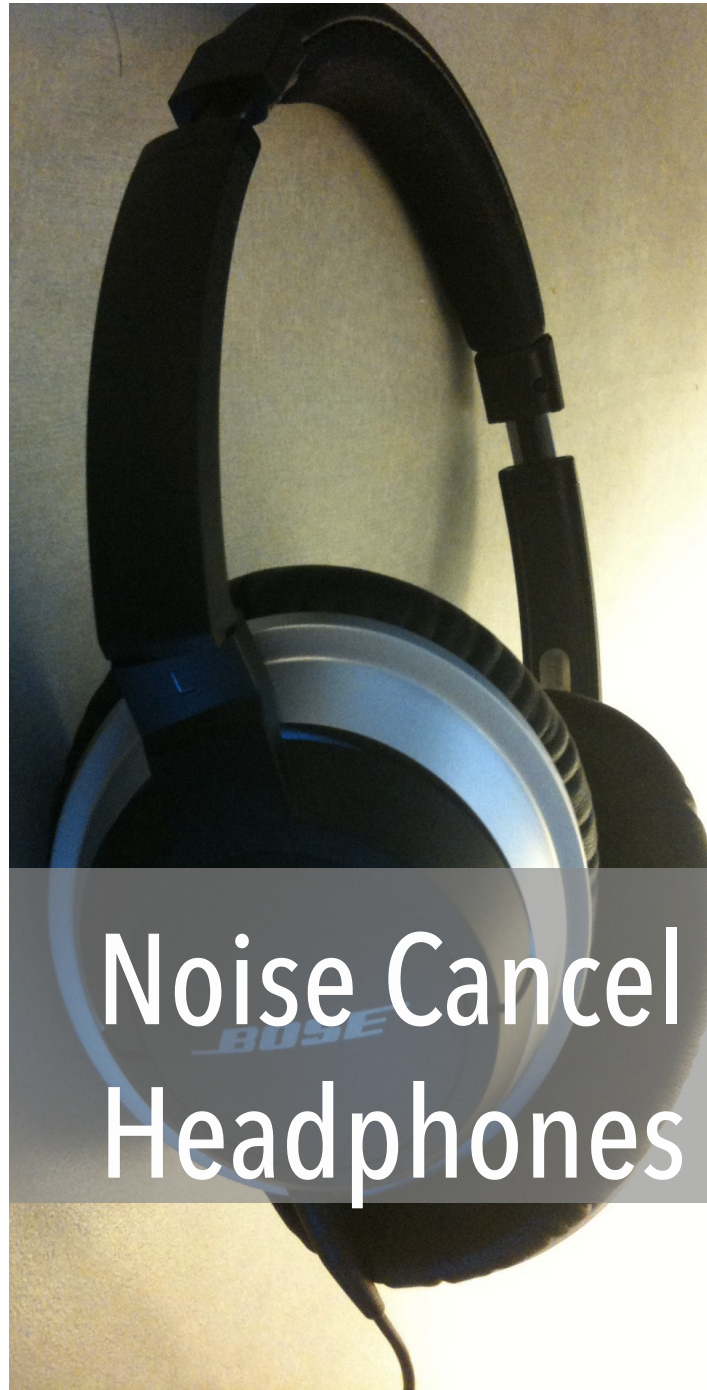
Some anglerfish, like those of the ceratioid group (Ceratiidae, or sea devils), employ an unusual mating method. Because individuals are locally rare, encounters are also very rare. Therefore, finding a mate is problematic. When scientists first started capturing ceratioid anglerfish, they noticed that all of the specimens were female. These individuals were a few centimetres in size and almost all of them had what appeared to be parasites attached to them. It turned out that these "parasites" were highly reduced male ceratioids. This indicates the anglerfish use a polyandrous mating system, in which two or more separate individuals "merge" into one for mating and feeding purposes. This, in a sense, makes the two initial heterogenous organisms a single one.



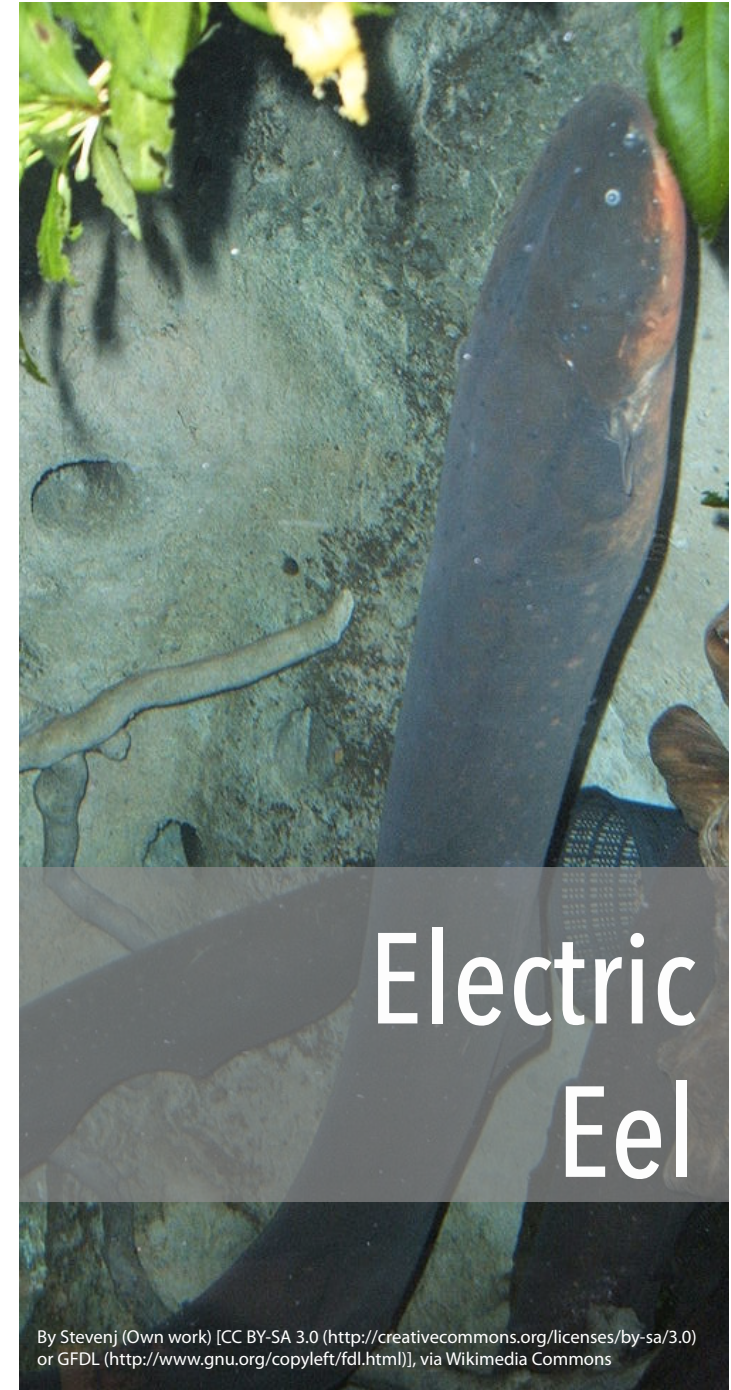
Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the coordination of components > Through the coordination of rhythms > Through the modification of the frequency or amplitude of a periodical action or energy.



Amplitude  
Modulation



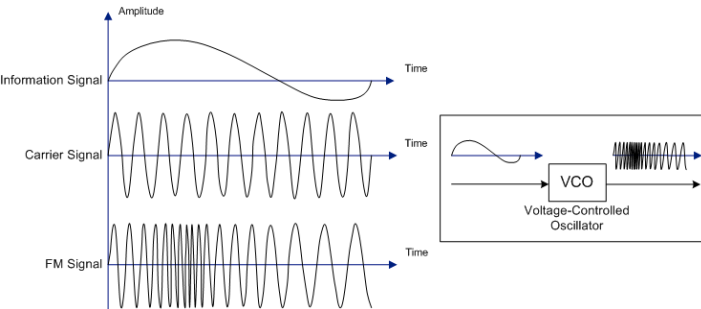
Noise Cancel  
Headphones



Electric  
Eel



Suppress/ reduce/displace/operate the problem > By acting on the generation/transmission/interaction/system > Through the coordination of components > Through the coordination of rhythms > Through the modification of the frequency or amplitude of a periodical action or energy.

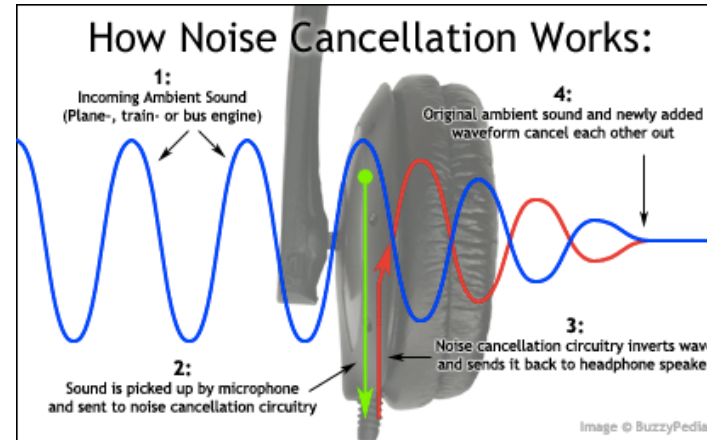


By Ivan Akira (Own work) [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

In telecommunications and signal processing, frequency modulation (FM) is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave.

Digital data can be encoded and transmitted via a carrier wave by shifting the carrier's frequency among a predefined set of frequencies—a technique known as frequency-shift keying (FSK). FSK is widely used in modems and fax modems, and can also be used to send Morse code. Radioteletype also uses FSK.

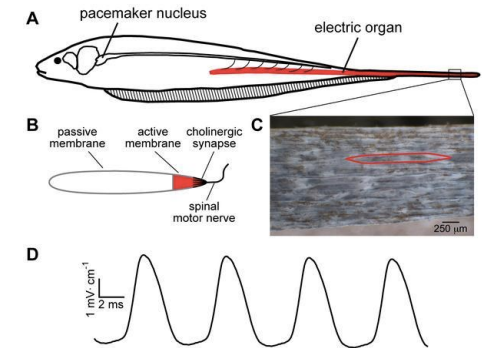
Frequency modulation is used in radio, telemetry, radar, seismic prospecting, and monitoring newborns for seizures via EEG. FM is widely used for broadcasting music and speech, two-way radio systems, magnetic tape-recording systems and some video-transmission systems. In radio systems, frequency modulation with sufficient bandwidth provides an advantage in cancelling naturally-occurring noise.



Noise-cancelling headphones are headphones that reduce unwanted ambient sounds using active noise control engineering.

Active noise control (ANC), also known as noise cancellation, or active noise reduction (ANR), is a method for reducing unwanted sound by the addition of a second sound specifically designed to cancel the first.

Sound is a pressure wave, which consists of a compression phase and a rarefaction phase. A noise-cancellation speaker emits a sound wave with the same amplitude but with inverted phase (also known as antiphase) to the original sound. The waves combine to form a new wave, in a process called interference, and effectively cancel each other out - an effect which is called phase cancellation



The Electric Organ.(figure from PLoS Biology, 2009;7(9): e1000203 DOI: 10.1371/journal.pbio.1000203))

The electric eel has three abdominal pairs of organs that produce electricity. When the eel locates its prey, the brain sends a signal through the nervous system to the electrocytes. This opens the ion channels, allowing sodium to flow through, reversing the polarity momentarily. By causing a sudden difference in electric potential, it generates an electric current. In the electric eel, electroplaques are capable of producing a shock at up to 600 volts and 1 ampere of current (600 watts) for a duration of two milliseconds.

They are capable of varying the intensity of the electric discharge, using lower discharges for "hunting" and higher intensities for stunning prey, or defending themselves. When agitated, they are capable of producing these intermittent electric shocks over a period of at least an hour without tiring.

The electric eel also possesses high-frequency-sensitive tuberous receptors, which are distributed in patches over its body. This feature is apparently useful for hunting other eels, which is called phase cancellation

Act on the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Through the evolution of the flow > Through the coordination of rhythms > Through the modification of the frequency or amplitude of a periodical action or energy.

## Pulse Width Modulation

0% Duty Cycle – analogWrite()



25% Duty Cycle – analogWrite()



50% Duty Cycle – analogWrite()

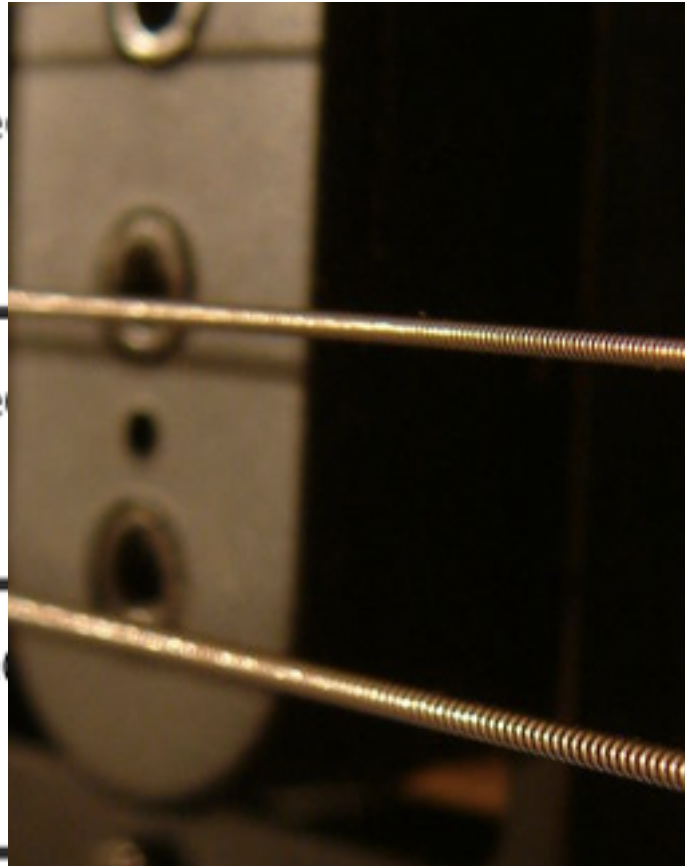
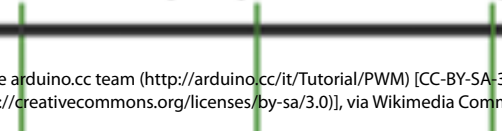


75% Duty Cycle – analogWrite()



# PWM

100% Duty Cycle – analogWrite()



# Guitar Strings

By Deelight. CC-BY-SA-2.5  
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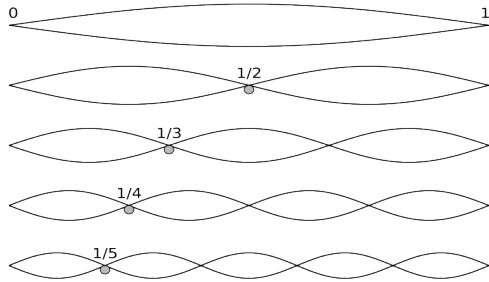
# Brown Bat

By [B. J. Brown](#). W.D. (U.S. Fish and Wildlife Service). [Public domain], via Wikimedia Commons

By The arduino.cc team (<http://arduino.cc/it/Tutorial/PWM>) [CC-BY-SA-3.0  
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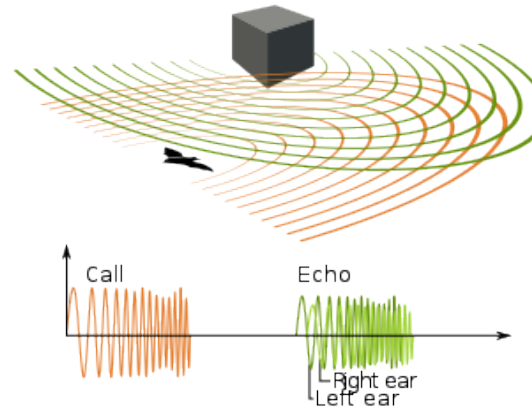


Act on the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Through the evolution of the flow > Through the coordination of rhythms > Through the modification of the frequency or amplitude of a periodical action or energy.



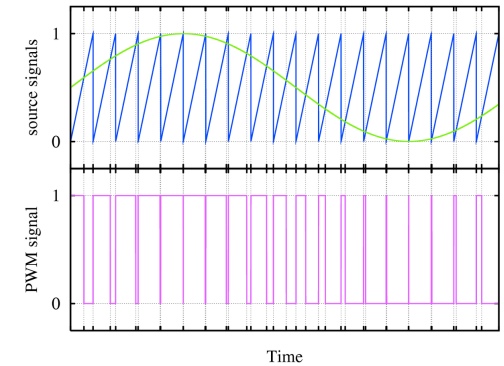
The strings of a guitar allow control of the pitch and harmonic content of the sound produced. The pitch is determined by the length, mass and tension of the strings. The produced frequencies are resonant frequencies of the strings, which depend inversely on the length (eg., cutting the length in half by depressing the string to the 12th fret will double the frequency to the note one octave up from the fundamental frequency of the string.) The mass and tension together determine the speed of the wave in the string. Since it is desirable to have about the same tension in each of the strings to keep from putting any distorting torque on the instrument, a matched set of strings will have carefully adjusted masses so that the strings are tuned to the correct intervals when the tensions are the same.

The bridge transfers the vibrational energy of the strings to the top plate of the instrument - the strings alone can't effectively move air to produce sound, but the vibrating top plate can do that quite efficiently.



The structure of a Continuous Frequency signal is adaptive in that it allows the bat to detect both the velocity of a target, and the fluttering of a target's wings as Doppler shifted frequencies.

A Doppler shift is an alteration in sound wave frequency, and is produced in two relevant situations: when the bat and its target are moving relative to each other, and when the target's wings are oscillating back and forth. CF-bats must compensate for Doppler shifts, lowering the frequency of their call in response to echoes of elevated frequency - this ensures that the returning echo remains at the frequency to which the ears of the bat are most finely tuned. The oscillation of a target's wings also produces amplitude shifts, which gives a CF-bat additional help in distinguishing a flying target from a stationary one



By Cyril B. [CC-BY-SA-3.0(<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

Pulse-width modulation (PWM) is a technique used to encode a message into a pulsing signal. It is a type of modulation. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible



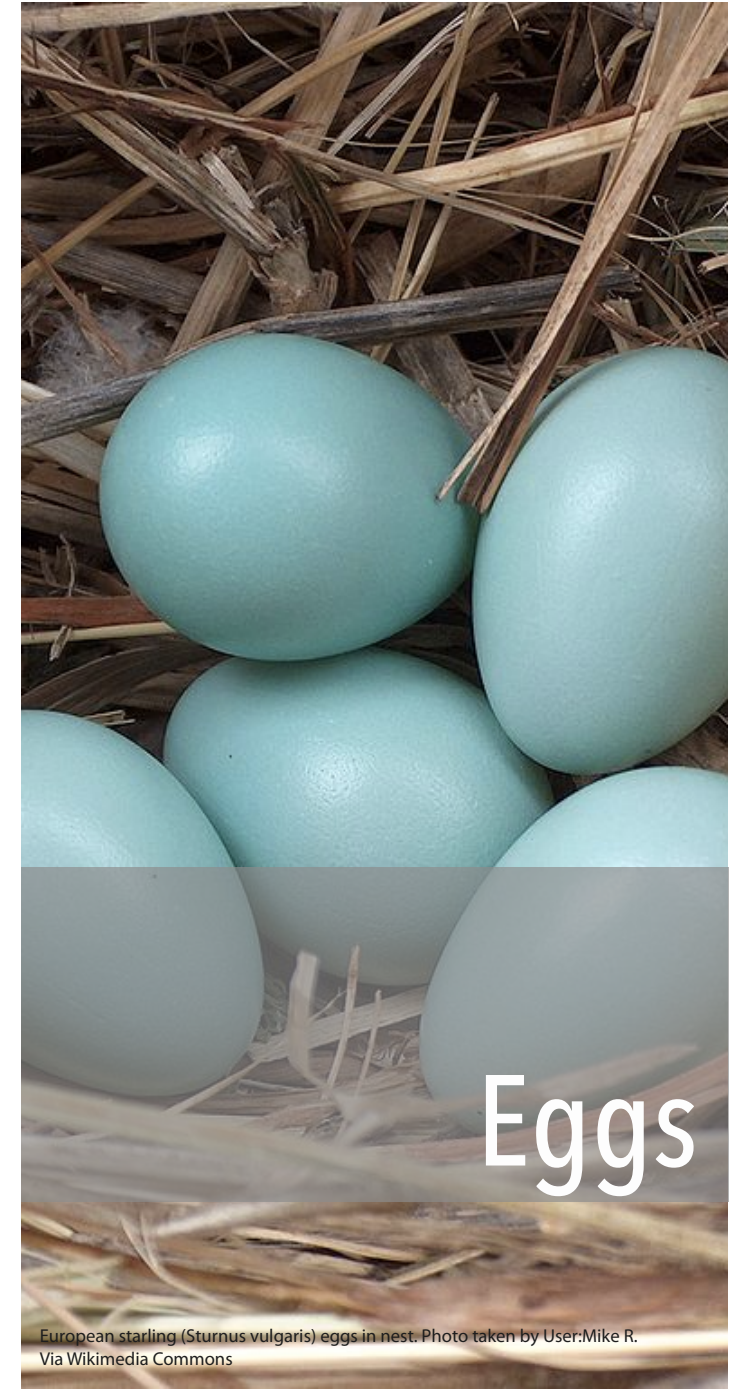
Act on the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the flow



# Plasma arc Cutting



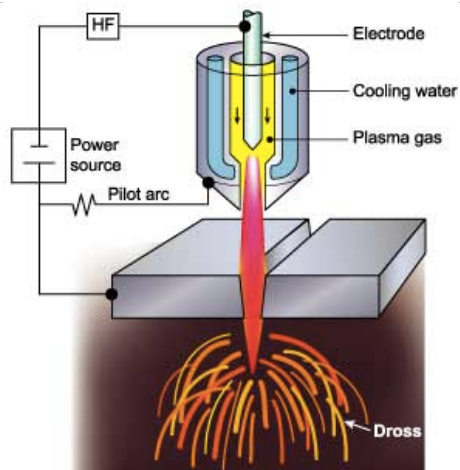
# Abrasive Blasting



# Eggs



Act on the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the flow



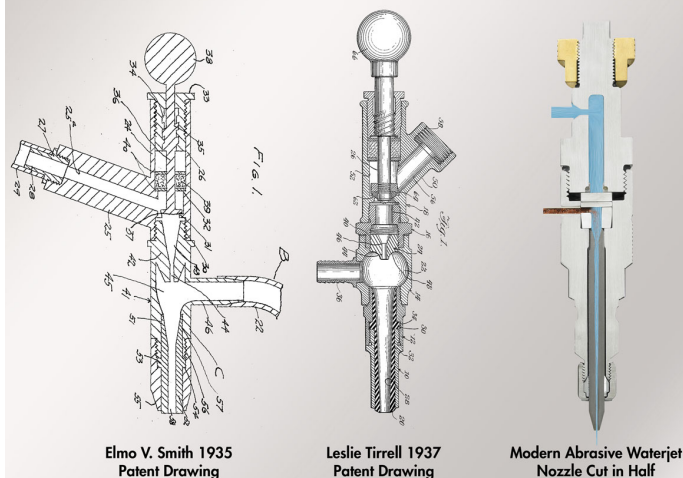
By TWI, via <http://www.twi-global.com/technical-knowledge/job-knowledge/cutting-processes-plasma-arc-cutting-process-and-equipment-considerations-051/>

Plasma cutting is a process that is used to cut steel and other metals of different thicknesses (or sometimes other materials) using a plasma torch. In this process, a gas (oxygen, air, inert and others dependant on material), which in this case acts as an intermediate flow between the arc and the material, is blown at high speed out of a nozzle; at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma.

When a gas is heated to extreme temperatures, the energy begins to break the gas molecules apart, splitting the atoms, which generates massive amounts of energy and incredible cutting power.

The plasma is hot enough to melt the metal being cut and moves fast enough to blow molten metal away from the cut.

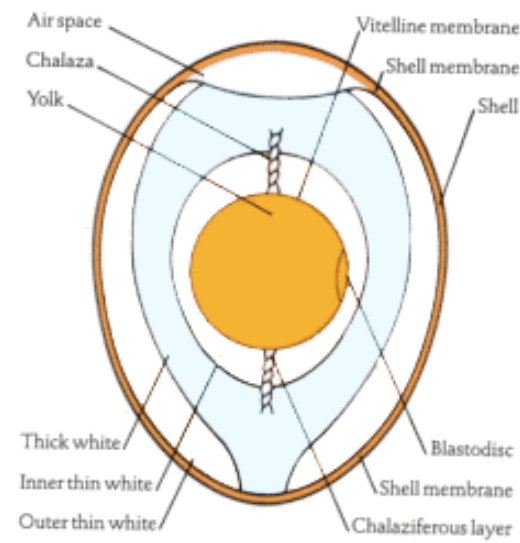
#### EVOLUTION OF MODERN ABRASIVE WATERJET NOZZLES



Evolution of the Abrasive Waterjet Nozzle by Cbrphoto. CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>), via Wikimedia Commons

Abrasive blasting is the operation of forcibly propelling a stream of abrasive material against a surface under high pressure to smooth a rough surface, roughen a smooth surface, shape a surface, or remove surface contaminants. A pressurized fluid, typically air, or a centrifugal wheel is used to propel the blasting material (often called the media).

There are several variants of the process, such as bead blasting, sand blasting, sodablasting, and shot blasting.



By My Farm Details, via <http://www.myfarmdetails.co.uk/site/standards/>

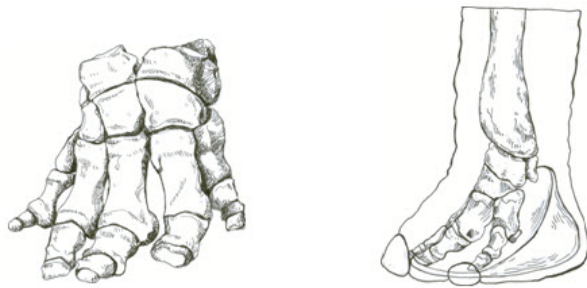
The egg's shock absorption is based on the fact that the embryo is surrounded by the albumen, an elastic gelatin-like substance of high water content. The result is a propitious combination of properties: a liquid that cannot be compressed, only displaced, and an elastic substance. When the embryo is pushed against the shell by some forceful impact, the liquid must flow past it and transform the destructive energy into heat. The shock absorption of the egg is further improved by an air cushion located at the thick end of the egg--the same end as the center of gravity. In a falling body the center of gravity moves to the lowest possible point, so in an egg the embryo falls on the air cushion. The air pocket in the egg has another mechanical function. It prevents temperature fluctuations from cracking the shell

Act on the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the flow > By passing from a planar contact (uniform mechanic field) to a point contact (discreet mechanical field) or viceversa.





Act on the problem > By acting on the generation/transmission/interaction/system > Through the modification of the components > Globally > Through the segmentation of the flow > By passing from a planar contact (uniform mechanic field) to a point contact (discreet mechanical field) or viceversa.

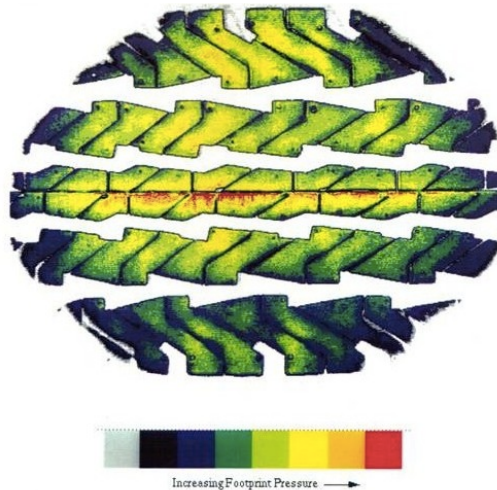


By vintik, via <http://vintika.net/news/7510-slon-hodit-na-cypochkah.html>

The uniquely designed limbs of the African elephant support the weight of the largest terrestrial animal. Besides other morphological peculiarities, the feet are equipped with large subcutaneous cushions which play an important role in distributing forces during weight bearing and in storing or absorbing mechanical forces.

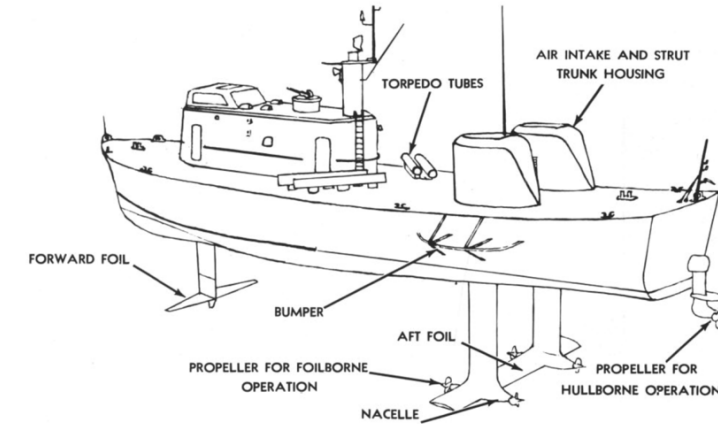
These cartilaginous rods support the metacarpal or metatarsal compartment of the cushions. None of the rays touches the ground directly, avoiding the entire load to be supported by the fingers, and widening the contact area.

The cushions consist of sheets or strands of fibrous connective tissue forming larger metacarpal/metatarsal and digital compartments and smaller chambers which are filled with adipose tissue.



Because a motorcycle is a single-track vehicle and leans as it turns, motorcycle tires are quite different than car tires. Whereas car tires have a fairly flat profile and a contact patch that varies little in size or shape, motorcycle tires have a U-shaped profile and a contact patch that changes size and shape during cornering. The shape of a motorcycle tire is designed to maintain a consistent contact patch throughout lean. A car tire in this application would be flat and fat when upright and thin and narrow when leaned.

The profile of a motorcycle tire clearly has one large-diameter ring in the middle that tapers to smaller rings at each side (creating the U-shape). As the bike leans, this makes rounding curves much easier than if the tires were square like those of a car.



A hydrofoil is a lifting surface, or foil, which operates in water. They are similar in appearance and purpose to airfoils used by airplanes.

As speed is gained, hydrofoils lift the boat's hull out of the water, minimising contact with water, therefore decreasing drag and thus allowing for greater speeds.

The hydrofoil usually consists of a wing-like structure mounted on struts below the hull, or across the keels of a catamaran in a variety of boats. As a hydrofoil-equipped watercraft increases in speed, the hydrofoil elements below the hull(s) develop enough lift to raise the hull out of the water in order to greatly reduce hull drag. This gives a further corresponding increase in speed and efficiency of operation in terms of fuel consumption.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Coordinating components ►  
Through the coordination of rhythms ► By increasing the frequency of vibration up to ultrasonic vibrations

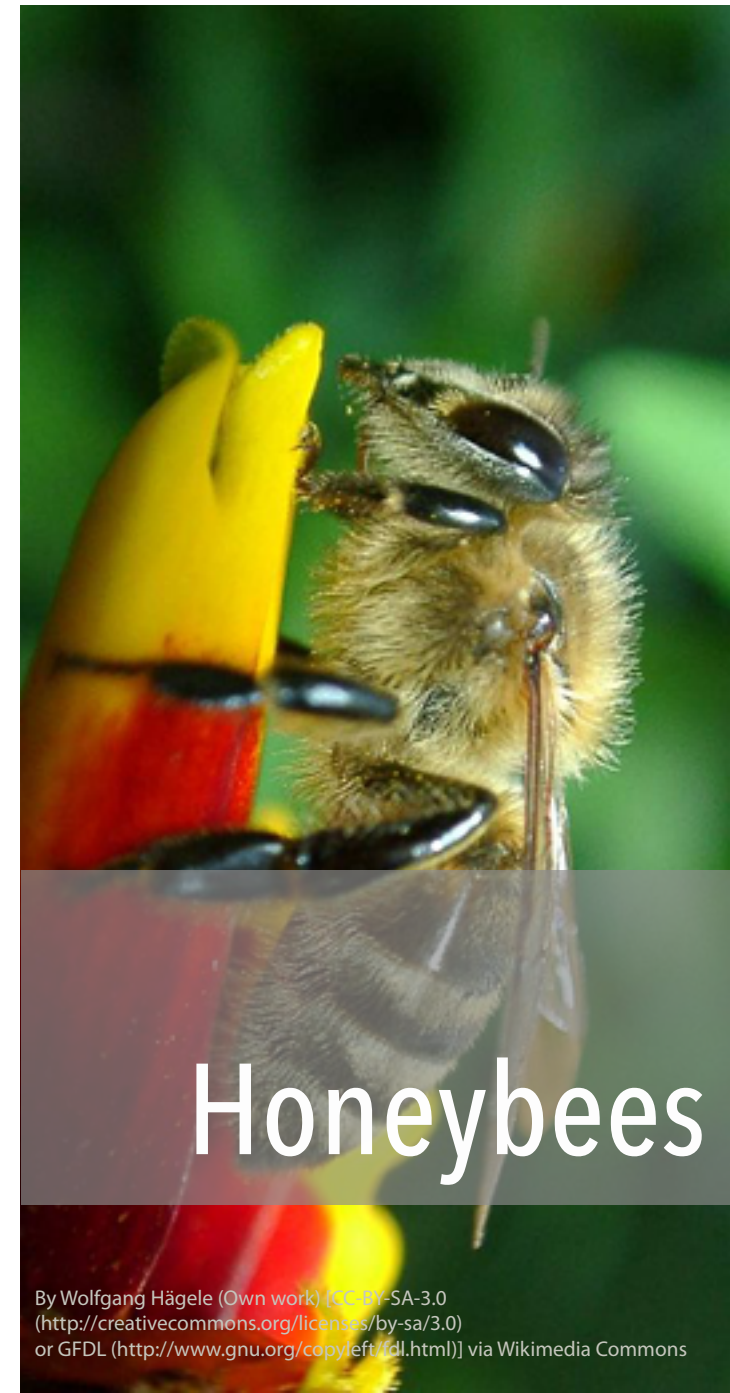


Ultrasonic  
Dispersion



Ultrasonic  
Toothbrush

By William Warby from London, England (Electric Toothbrush Head)  
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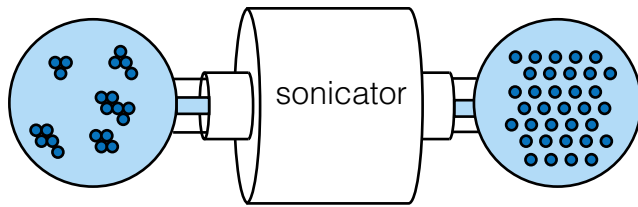


Honeybees

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Act on the problem ► By acting on the generation/transmission/interaction systems ► Coordinating components ►  
Through the coordination of rhythms ► By increasing the frequency of vibration up to ultrasonic vibrations



The dispersing and deagglomeration of solids into liquids is an important application of ultrasonic devices. Ultrasonic cavitation generates high shear that breaks particle agglomerates into single dispersed particles. The mixing of powders into liquids is a common step in the formulation of various products, such as paint, ink, shampoo, beverages, or polishing media. The individual particles are held together by attraction forces of various physical and chemical nature, including van der Waals forces and liquid surface tension. This effect is stronger for higher viscosity liquids, such as polymers or resins. The attraction forces must be overcome in order to deagglomerate and disperse the particles into liquid media. The application of mechanical stress breaks the particle agglomerates apart. Also, liquid is pressed between the particles. High intensity ultrasonication is an interesting alternative to these technologies. When sonicating liquids the sound waves that propagate into the liquid media result in alternating high-pressure (compression) and low-pressure (rarefaction) cycles. This applies mechanical stress on the attracting electrostatic forces.



An ultrasound toothbrush is a type of electric toothbrush whose bristles vibrate at an ultrasonic frequency when activated. This vibration creates small bubbles, which augment normal brushing action to help break up and remove particles on the teeth. Ultrasonic toothbrushes are considered more effective than traditional manual toothbrushes when used correctly and regularly.

These brushes are capable of creating in excess of 30,000 brush-strokes-per-minute. In comparison, conventional electric toothbrushes typically operate at frequencies ranging between 2,500 and 7,500 strokes-per-minute.

This bristle motion is able to impart energy to the fluids that surround teeth (such as saliva). In turn, these agitated fluids are able to disrupt dental plaque, even beyond where the bristles actually touch



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Sonication or buzz pollination is a technique used by some bees to release pollen which is more or less firmly held by the anthers, which makes pollination more efficient. The anther of buzz-pollinated species of plants is typically tubular, with an opening at only one end, and the pollen is inside - smooth-grained and firmly attached. With self-fertile plants such as tomatoes, wind may be sufficient to shake loose the pollen through pores in the anther and accomplish pollination. Visits by bees may also shake loose some pollen. However, the most efficient pollination is accomplished by a few species who specialize in sonication or buzz pollination.

In order to release the pollen, bumblebees and some species of solitary bees are able to grab onto the flower and move their flight muscles rapidly, causing the flower and anthers to vibrate, dislodging pollen. This resonant vibration is called buzz pollination.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components  
Through the adaptation of components ► Through the evolution of materials ► Changing phase



# Phase Change Materials



# PCM Insulation

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# Titan Arum

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Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components  
Through the adaptation of components ► Through the evolution of materials ► Changing phase



Titan Arum is such a large plant that it can take a year or more for the plant to store enough energy to bloom (and even then, the plant can only sustain its bloom for a couple of days). Because Titan Arum plants are located so far apart from one another and bloom so infrequently, they need to attract as much insect attention as possible to ensure pollination. The corpse flower uses its smell to attract sweat bees and beetles looking for a prime location to lay their eggs. By crawling all over the plant, these insects play a vital role in pollinating the Titan Arum.

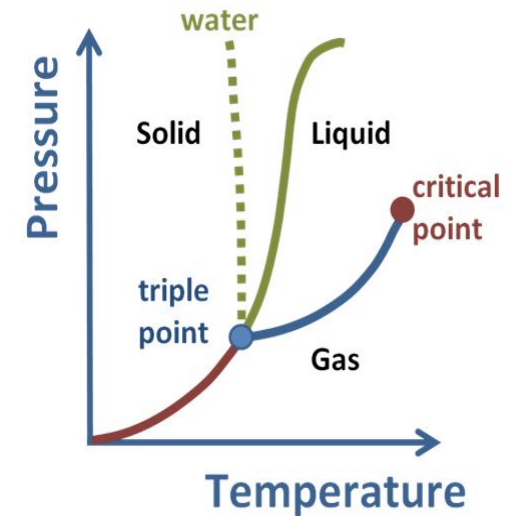
To produce its perfume, the plant raises its internal temperature several degrees above that of its surroundings and provokes a change of state in the oils secreted in its heart, vaporising them.



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Phase Change materials store and release heat at pre-set temperatures. These materials are engineered around the fundamental property of natural material of absorbing heat when they melt, and releasing heat when they solidify.

When these Phase Change Materials are placed in quantity into the structure of a building, they can execute the purpose of isolating said structure by absorbing heat during the day and releasing it during the night, making the energy consumption of buildings more efficient and less costly.



By Brews ohare (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)], via Wikimedia Commons

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa.

Initially, their temperature rises as they absorb heat. And when PCMs reach the temperature at which they change phase they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the shape ► Optimized according to CdCF criteria ► Size



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Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the shape ► Optimized according to CdCF criteria ► Size



Size is no accident in nature. It is tailored to many conditions: the effect of external forces - gravity, water pressure, temperature, light, humidity, and so on; the quality, quantity, and availability of food; the number and nearness of predators, kin, and mates. At all times, size is governed by geometric laws that dictate whether an insect can grow as big as an elephant, or why a Shire horse is a different shape to a Shetland pony

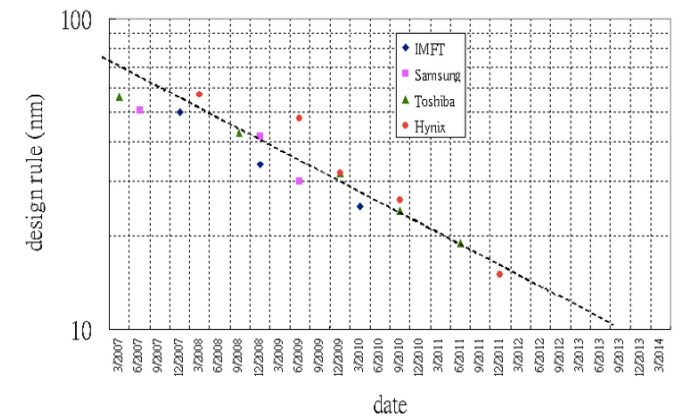
As a matter of fact, ponies originally developed as a landrace adapted to a harsh natural environment, and were considered part of the "draft" subtype typical of Northern Europe.

The ancestors of most modern ponies developed small stature due to living on the margins of livable horse habitat. These smaller animals were domesticated and bred for various purposes all over the northern hemisphere.



What sets the MacBook Air apart from other clunky laptops on the market is its size -- it's less than an inch thick and weighs fewer than 3 pounds. That means you can toss it in a backpack, messenger bag or average-sized purse and barely know it's there. When it was first introduced in 2008, the thickness of the computer, when closed, varied between .76 inches at its thickest point and .16 inches at its thinnest. But if you think that's small, consider the fact that over the years the computer has gotten even thinner: The 2011 models were between .68 and .11 inches thick

At just under 3 pounds, the Air is Apple's lightest laptop yet -- a full 2 pounds lighter than its predecessor, the MacBook. It has an aluminum body, which gives it that sleek, industrial look. But the exterior design is also practical, because the aluminum shell is more durable and resistant to scratches than a plastic body. So even though it's thin and looks a little flimsy, the body is surprisingly strong



Guiding light at English Wikipedia [CC-BY-SA-3.0-2.5-2.0-1.0 (http://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons

Gordon Moore gave name to the law that has been dominating the microprocessor evolution over the last 45 years. Moore's law is the observation that, over the history of computing hardware, the number of transistors in a dense integrated circuit doubles approximately every two years.

The capabilities of many digital electronic devices are strongly linked to Moore's law: quality-adjusted microprocessor prices, memory capacity, sensors and even the number and size of pixels in digital cameras. All of these are improving at roughly exponential rates as well

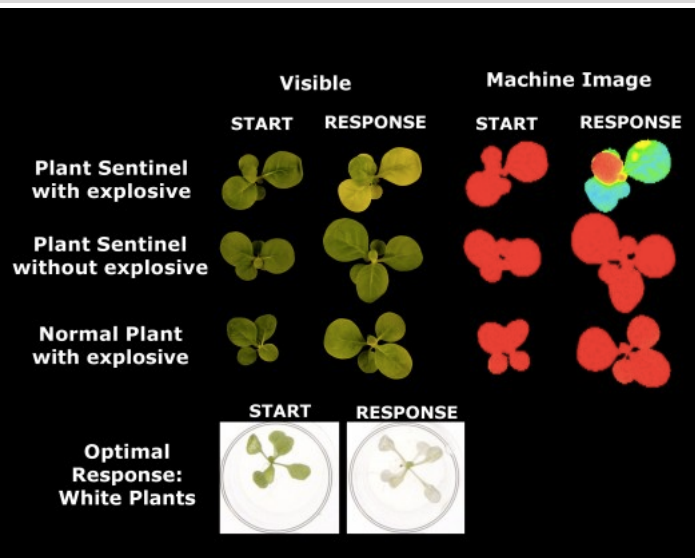
Moore himself declared in 2005 that the law named after him was dead, when he said: "In terms of size you can see that we're approaching the size of atoms which is a fundamental barrier



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally  
Through the adaptation of components ► Through the evolution of materials ► Towards materials with properties that  
change over time



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally  
Through the adaptation of components ► Through the evolution of materials ► Towards materials with properties that change over time

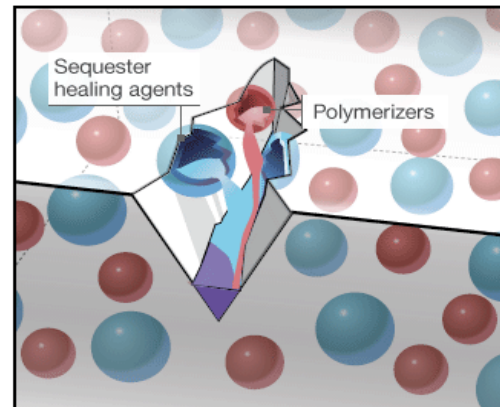


Plants such as tobacco are as good as or better than a dog's nose for detecting airborne substances. Unlike dogs, however, plants don't need to be trained, housed or fed. They also don't need to be powered or protected from the elements, unlike electronics.

With help from colleagues at Duke University and the University of Washington, Medford redesigned naturally-occurring receptor proteins using a computer program. She then modified the receptors to function in plants, and targeted them to the test plants' cell walls.

In the first generation of plants, the receptors were able to detect pollutants and explosives in the air or soil near each plant, and caused chlorophyll suppression within a matter of hours

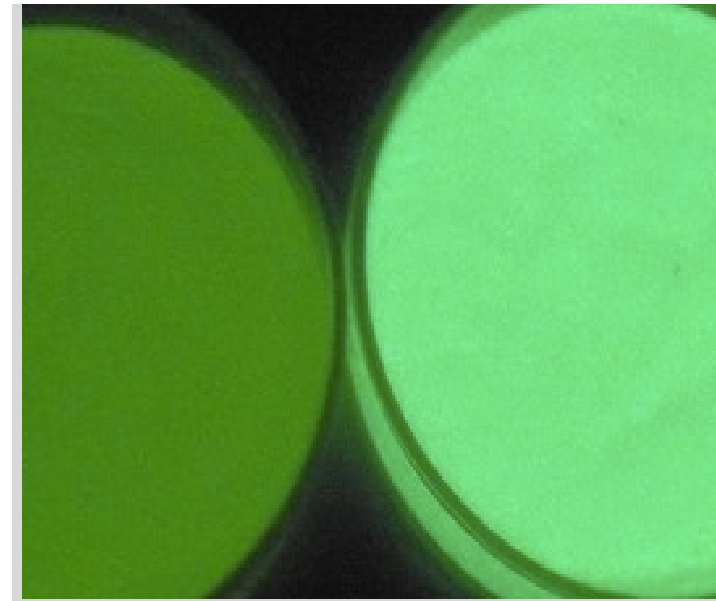
Capsule-based



Source: Janet Sinn-Harlon, Scott White, Ben Blaiszik

<http://aerospaceengineeringblog.com/developments-in-composite-materials/>

Self-healing materials are a class of smart materials that have the structurally incorporated ability to repair damage caused by mechanical usage over time. The inspiration comes from biological systems, which have the ability to heal after being wounded. Initiation of cracks and other types of damage on a microscopic level has been shown to change thermal, electrical, and acoustical properties, and eventually lead to whole scale failure of the material. A material that can intrinsically correct damage caused by normal usage could lower costs of a number of different industrial processes through longer part lifetime, reduction of inefficiency over time caused by degradation, as well as prevent costs incurred by material failure. For a material to be strictly defined as self-healing, it is necessary that the healing process occurs without human intervention



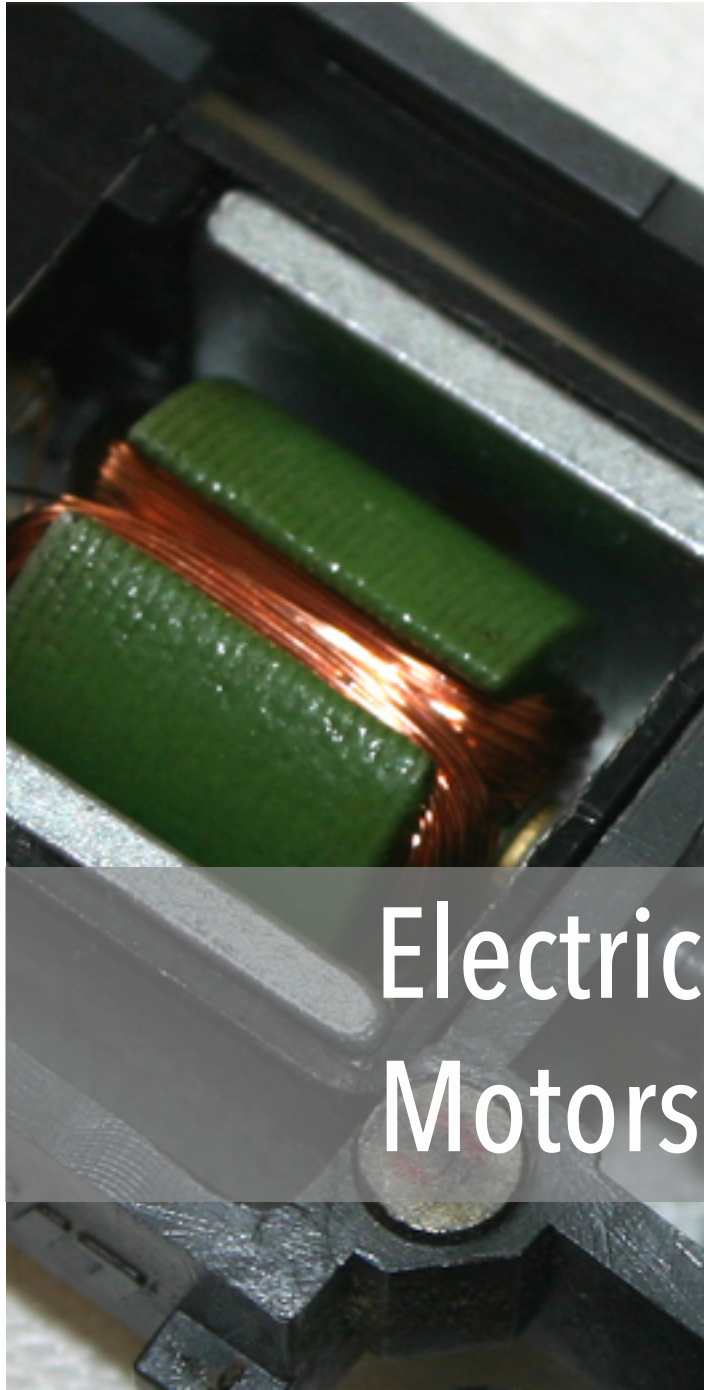
In simple terms, phosphorescence is a process in which energy absorbed by a substance is released relatively slowly in the form of light. This is in some cases the mechanism used for "glow-in-the-dark" materials which are "charged" by exposure to light. Unlike the relatively swift reactions in fluorescence, such as those seen in a common fluorescent tube, phosphorescent materials "store" absorbed energy for a longer time, as the processes required to re-emit energy occur less often.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Coordinating components ►  
Following the logic of MATHEM field evolution ► Through the utilization of a magnetic, electric or electromagnetic field



Maglev



Electric  
Motors



Whale's  
Navigation



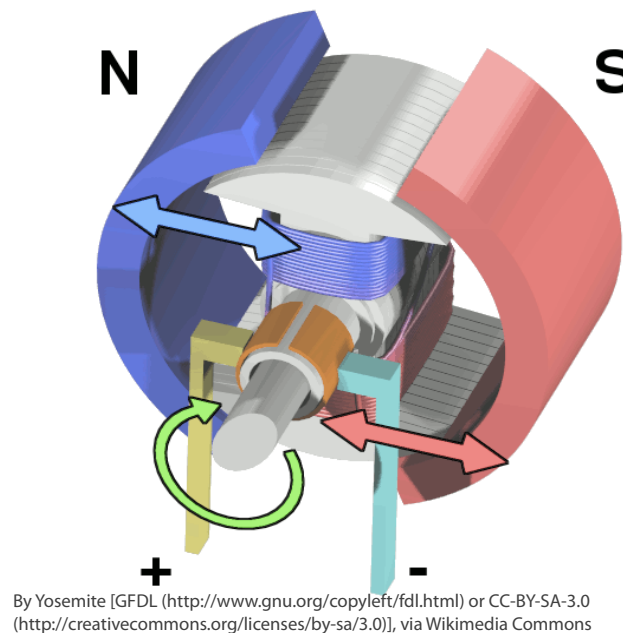
Act on the problem ► By acting on the generation/transmission/interaction systems ► Coordinating components ►  
Following the logic of MATHEM field evolution ► Through the utilization of a magnetic, electric or electromagnetic field



Each year, whales migrate from Hawaii to the northern Pacific coast, and back. How do they manage to find the tiny islands in that vast sea? Sonar may help them stay together and follow one another, but they must use some other means to remember and relocate their destination.

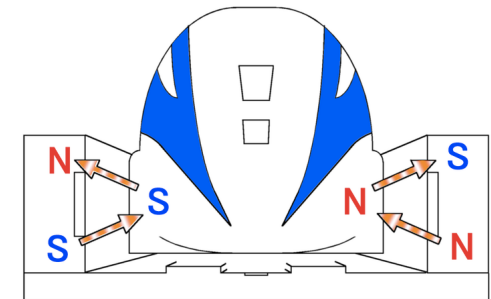
Many researchers believe whales use biomagnetism to do this. We already know about lots of animals and birds that use magnetic material in their bodies to help them understand where they are.

Biomagnetite has been found in the brains of whales and dolphins, and it is widely believed that marine mammals use magnetism as well as sonar to direct themselves during migration.



An electric motor is an electric machine that converts electrical energy into mechanical energy.

Most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor. In certain applications, such as in the transportation industry with traction motors, electric motors can operate in both motoring and generating or braking modes to also produce electrical energy from mechanical energy.



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Maglev (derived from magnetic levitation) is a method of transportation that uses magnetic levitation to carry vehicles with magnets. With maglev, a vehicle is levitated a short distance away from a guide way using magnets to create both lift and propulsion.

The power needed for levitation is typically not a large percentage of the overall energy consumption; most of the power is used to overcome air resistance, as with any other high-speed form of transport.

There are two types of maglev technology:

- For electromagnetic suspension (EMS), electronically controlled electromagnets in the train attract it to a magnetically conductive track.

- .Electrodynamic suspension (EDS) uses superconducting electromagnets or strong permanent magnets which create a magnetic field that induces currents in nearby metallic conductors when there is relative movement which pushes and pulls the train towards the designed levitation position on the guide way.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Rearranging components ► Changing the orientation of a component ► Into horizontal, vertical, inclined or inverse positions



Translohr

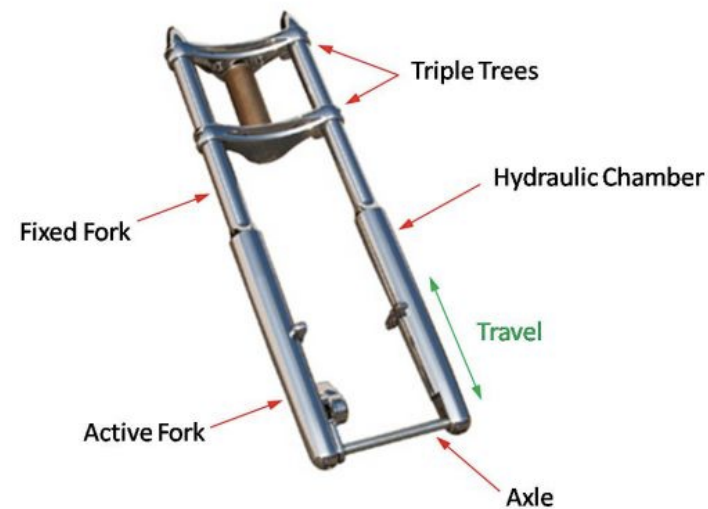


Inverted Fork



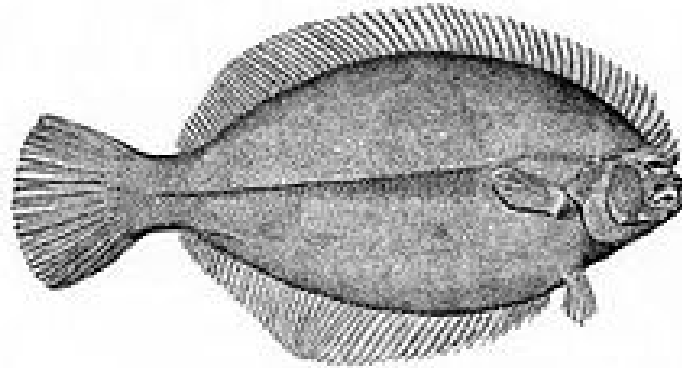
Flatfish

Act on the problem ► By acting on the generation/transmission/interaction systems ► Rearranging components ► Changing the orientation of a component ► Into horizontal, vertical, inclined or inverse positions



A telescopic fork uses fork tubes which contain the suspension components (coil springs and damper) internally.

Conventionally, the fork stanchions are at the top, clamped to a triple tree (also called a triple clamp or a yoke), and the sliders are at the bottom, attached to the front wheel spindle. On some modern sport bikes and most off-road bikes, this system is inverted, with "sliders" (complete with the spring/damper unit) at the top, clamped to the yoke, while the stanchions are at the bottom. This is done (i) to reduce unsprung weight by having the lighter components suspended, and (ii) to improve the strength and rigidity of the assembly by having the strong large-diameter "sliders" clamped in the yokes



All living flatfishes, which include halibut, flounder and sole, have a bizarre structural adaptation: both eyes are on one side of their head. What is even more remarkable is that every flatfish is born symmetrical, with one eye on each side of its skull. However, as it develops from a larva to a juvenile, it undergoes a metamorphosis where one eye moves (or "migrates") gradually up and over the top of the head, coming to rest in its adult position on the opposite side of the skull.

This unique specialization provides a clear survival advantage: it allows flatfishes to use both of their eyes to look up when they are lying on the seafloor.



Translohr runs on rubber tires and is guided by a single central rail.

The Translohr system is intended to provide a much more light rail-like experience than that provided by buses. Unlike other guided bus systems (including the similar but incompatible Guided Light Transit system developed by Bombardier Transportation), Translohr can run only where there is a guide rail in place as there are no steering controls. Like a conventional tram, power is provided by overhead wires and collected with a pantograph, although the vehicle can also run on internal batteries

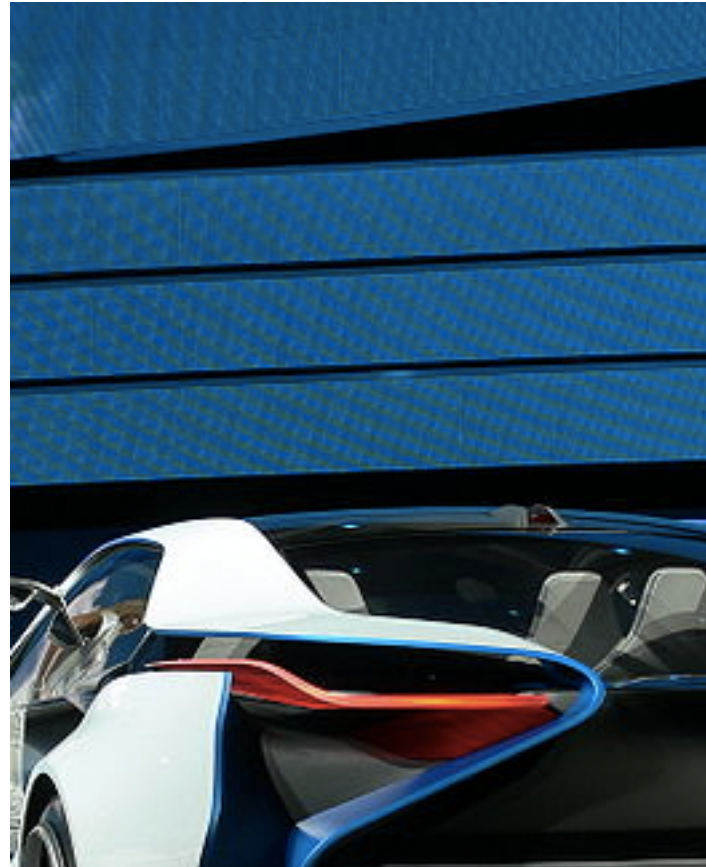
The diagram shows the central guide rail (green) and the vehicle's guide wheels (red), which grasp the rail perpendicular to each other, helping to avoid derailments.



Act on the problem ► By acting on the generation/transmission/interaction systems ►  
Rearranging components ► For a better usage of energy



## Mac Pro Tower



## BMW Efficient Dynamics

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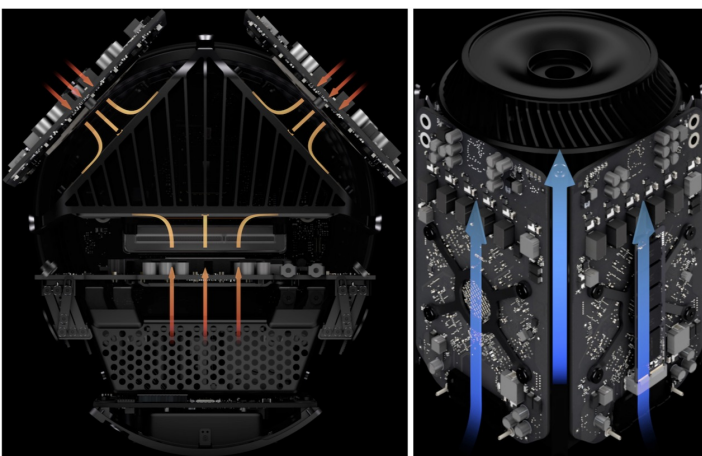


## Birds V-Formation

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Act on the problem ► By acting on the generation/transmission/interaction systems ►  
Rearranging components ► For a better usage of energy



All of the components responsible for the heavy lifting in the Mac Pro are arranged around a unique thermal core, a single piece of extruded aluminum serving as a heat sink for the entire machine. The design, which also maximizes airflow, allows the heat sink to maximize heat transfer under a variety of different load conditions, offering better performance than with separate heat sinks for each component.

That thermal core is responsible for the cylindrical design of the new Mac Pro, with the machine being topped a single large vertically mounted fan that draws air up from the bottom and through the thermal core before venting it out through the top. By optimizing fan blade size, shape, and number, Apple has been able to minimize air resistance, increasing efficiency while keeping fan noise to a minimum.



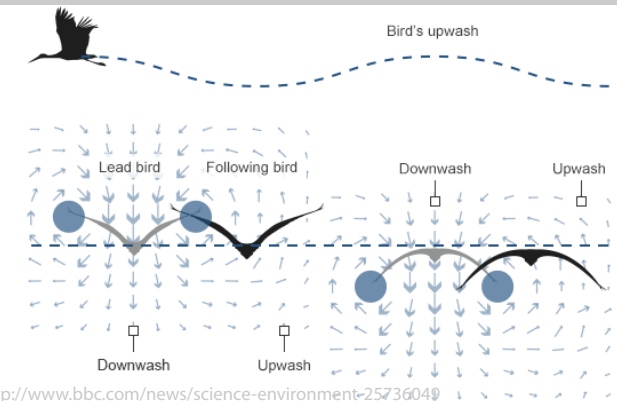
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BMW's EfficientDynamics technology includes a wide range of other features. This technology has helped BMW achieve outstanding fuel economy and low emissions.

-Auto Start-Stop - The engine stops whenever the car comes to rest and is taken out of gear, restarting the second the clutch is depressed.

-Intelligent Alternator Control / Brake Energy Regeneration - The alternator disengages automatically when the battery is fully charged, only re-engaging when the battery needs charging. In addition, the system engages automatically when the vehicle is braking or coasting, to recycle wasted energy.

-Electric Power Steering - Replacing the conventional hydraulic system saves weight and fuel and allows assistance to be varied at lower speeds.



<http://www.bbc.com/news/science-environment-25736049>

Source: Nature

Compared with solo flight, formation flight confers a significant aerodynamic advantage which allows birds to reduce their energy expenditure while flying at a similar speed. In birds flying in formation, each wing moves in an upwash field that is generated by the wings of the other birds in the formation. Modelling has shown that when birds are flying with optimal spacing, a maximal reduction in power can be achieved and total transport costs can be substantially reduced.

When flying in formation, pelicans appear to beat their wings less frequently and to glide for longer periods

The main benefit of flight formation, which until now has not been recognized, could be that by flying in a vortex wake, pelicans are able to glide for a greater proportion of their total flight time, with the total energy savings of 11.4–14.0% being achieved primarily through this strategy



Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ►  
Through the evolution of the flow For the reduction of deformations ► Passing from a rigid to a deformable system through the  
modification of the behaviour of the components, from traction or compression to traction+compression (truss) and flexion



Suspension  
Bridge



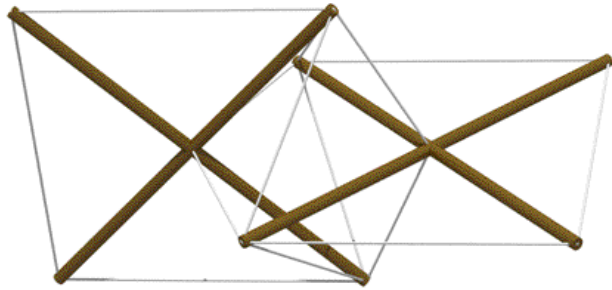
Tensegrity  
Structure

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Broad  
Leaves

Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ► Through the evolution of the flow For the reduction of deformations ► Passing from a rigid to a deformable system through the modification of the behaviour of the components, from traction or compression to traction+compression (truss) and flexion



"Snelson XModule Design 1948" by Bob Burkhardt - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Snelson\\_XModule\\_Design\\_1948.png#mediaviewer/File:Snelson\\_XModule\\_Design\\_1948.png](http://commons.wikimedia.org/wiki/File:Snelson_XModule_Design_1948.png#mediaviewer/File:Snelson_XModule_Design_1948.png)

Tensegrity, tensional integrity or floating compression, is a structural principle based on the use of isolated components in compression inside a net of continuous tension, in such a way that the compressed members (usually bars or struts) do not touch each other and the prestressed tensioned members (usually cables or tendons) delineate the system spatially.

Tensegrity structures are structures based on the combination of a few simple design patterns:

- Loading members only in pure compression or pure tension, meaning the structure will only fail if the cables yield or the rods buckle
- Preload or tensional prestress, which allows cables to be rigid in tension
- Mechanical stability, which allows the members to remain in tension/compression as stress on the structure increases

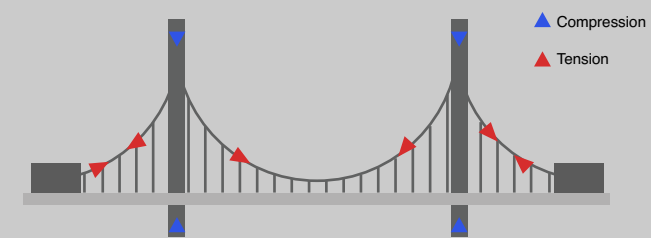
Because of these patterns, no structural member experiences a bending moment. This can produce exceptionally rigid structures for their mass and for the cross section of the components.



The growth responses of wood are controlled locally. The tree lays down wood where the mechanical stresses are highest, ensuring that wood is laid down only where it is actually needed. This facility is responsible for many aspects of the shape of trees. It ensures that branches are strongly joined to the trunk by expanding like the bell of a trumpet at their base; stresses are concentrated where the branches join the trunk and this causes the branch automatically to grow thicker there.

The response also causes lateral roots, which are bent only in the vertical plane, to grow fastest along their tops and bottoms, and so develop into mechanically efficient I-beam shapes.

The broad leaf of a tree resists gravitational loading through its internal anisotropic structure: liquid-filled cells along the bottom resist compression, and, along the top, long cells with lengthwise fibers resist tension



The main forces in a suspension bridge of any type are tension in the cables and compression in the pillars. Since almost all the force on the pillars is vertically downwards and they are also stabilized by the main cables, the pillars can be made quite slender

Assuming a negligible weight as compared to the weight of the deck and vehicles being supported, the main cables of a suspension bridge will form a parabola (very similar to a catenary, the form the unloaded cables take before the deck is added). One can see the shape from the constant increase of the gradient of the cable with linear (deck) distance, this increase in gradient at each connection with the deck providing a net upward support force. Combined with the relatively simple constraints placed upon the actual deck, this makes the suspension bridge much simpler to design and analyze than a cable-stayed bridge, where the deck is in compression.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ►  
Through the evolution of the shape ► Changing the spatial dimension, from 1D to 2D, up to 3Ds  
► Following the evolution: linear, planar, curved.

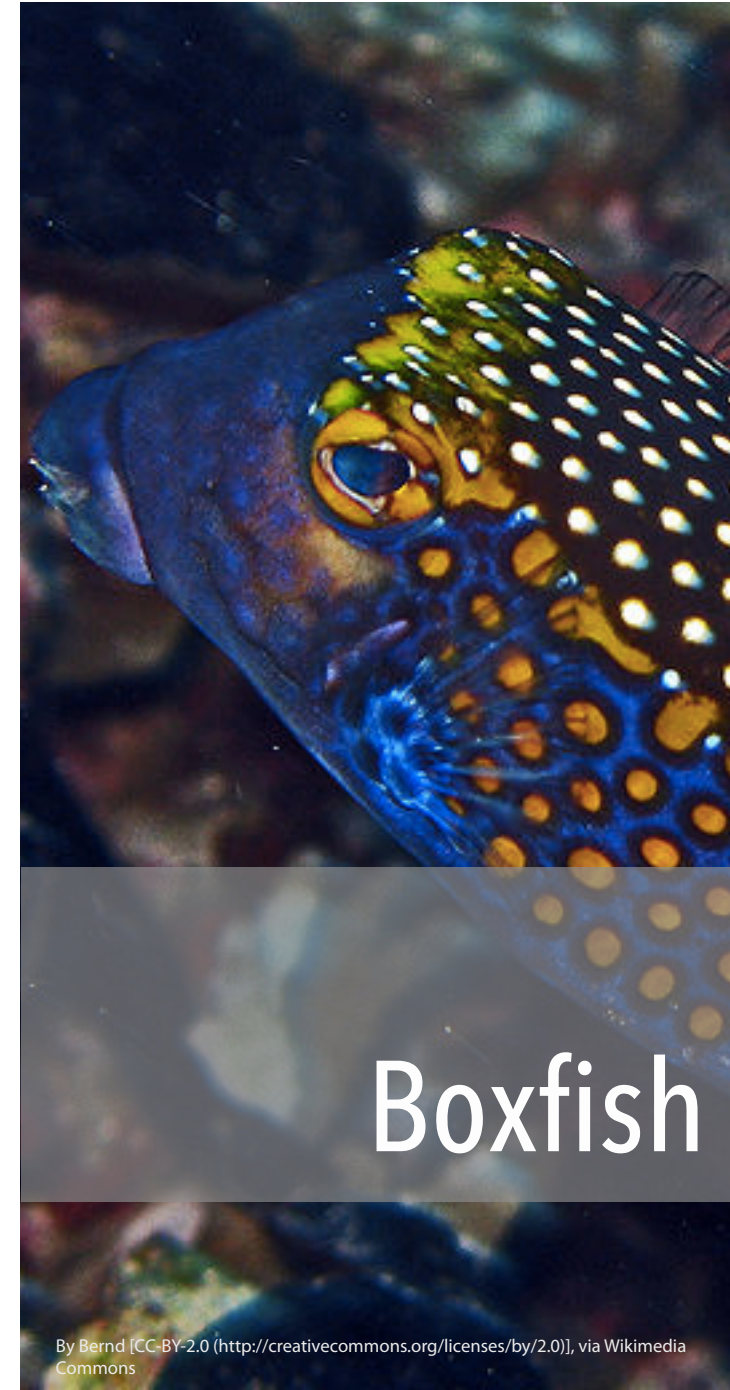


Lens  
Optics



Concave  
Football Shoes

Concave (r) by Prodirectsoccer. <http://www.prodirectsoccer.com/es/Products/Botas-de-F%C3%BAtbol-Tacos-Concave-Terreno-Blando-Concave-Quantum-SG-Blanco-Rojo-65442.aspx>



Boxfish

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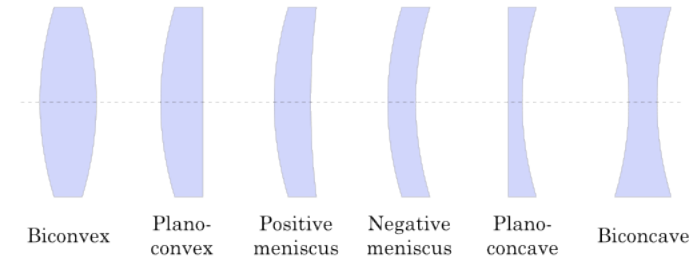
Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ►  
Through the evolution of the shape ► Changing the spatial dimension, from 1D to 2D, up to 3Ds  
► Following the evolution: linear, planar, curved.



The Concave football boot is a special boot designed to increase the 'sweet spot' (the area of the boot that makes contact with the ball) by approximately four times. It has evolved the games of Australian Football League, Soccer and Rugby League. Independent testing at Deakin University has shown the boot increases power by between 8-15% and provides increased accuracy with a smaller margin of error. Concave also designed this new boot to protect the metatarsal bones



Thanks to its body plan, the boxfish is able to resist the forces of turbulent water in a unique way. Due to its trapezoidal or triangular shape, and flattened back (its keel), the boxfish is able to create self-stabilizing vortices using the turbulent water itself. The water passes over the flat front of the fish's keel, before the pointed back portion divides the water towards the fish's concave (curved inward) sides. Acting like train tracks, grooved scales and stiff bumps along the sides of the boxfish transport the water, like a train, turning the water about in order to create vortices. These newly created vortices then move away from the organism and towards the opposite side of the water's origin.



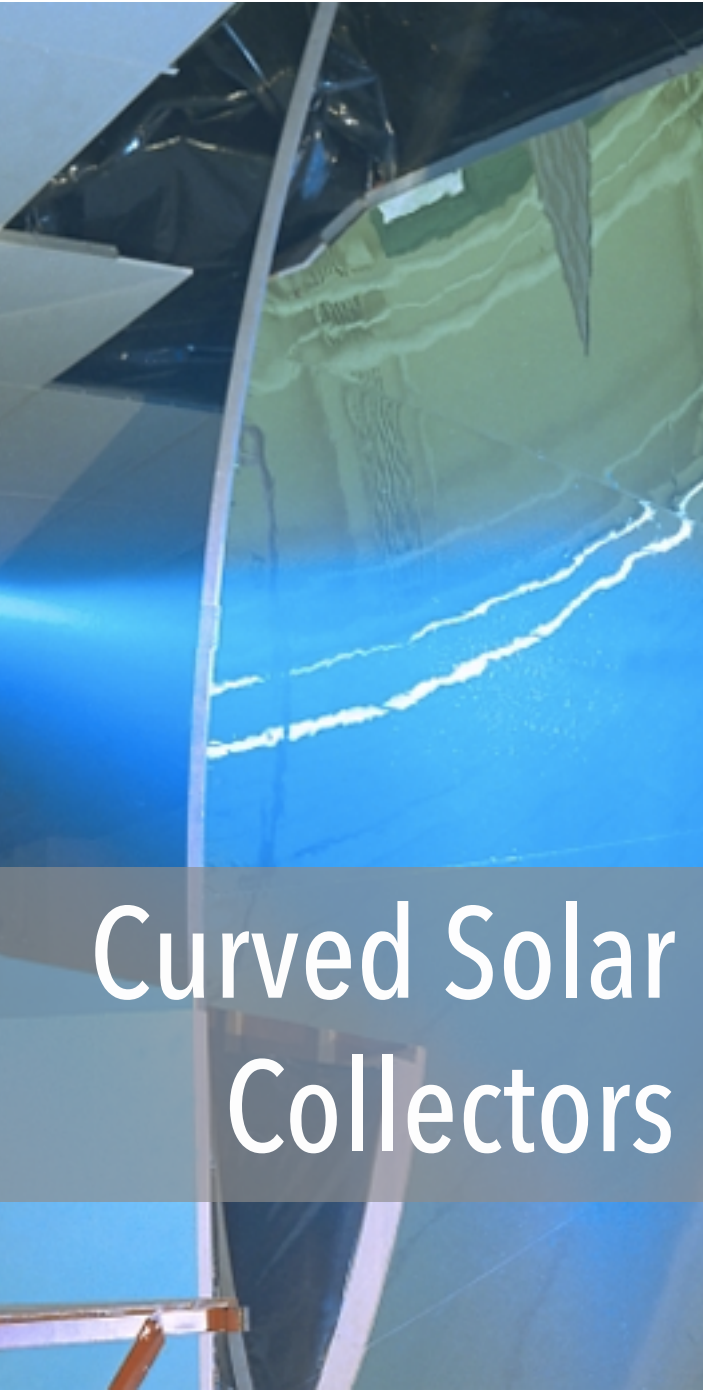
By ElfQrin (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

Lenses are classified by the curvature of the two optical surfaces. A lens is biconvex if both surfaces are convex. If both surfaces have the same radius of curvature, the lens is equiconvex. A lens with two concave surfaces is biconcave. If one of the surfaces is flat, the lens is plano-convex or plano-concave depending on the curvature of the other surface. A lens with one convex and one concave side is convex-concave or meniscus. It is this type of lens that is most commonly used in corrective lenses.

If the lens is biconvex or plano-convex, a collimated beam of light passing through the lens will be converged (or focused) to a spot behind the lens. In this case, the lens is called a positive or converging lens. If the lens is biconcave or plano-concave, a collimated beam of light passing through the lens is diverged (spread); the lens is thus called a negative or diverging lens. An ideal thin lens with two surfaces of equal curvature would have zero optical power, meaning that it would neither converge nor diverge light.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ►  
Through the evolution of the shape ► Changing the spatial dimension, from 1D to 2D, up to 3Ds  
► Following the evolution: linear, planar, curved.



Curved Solar  
Collectors

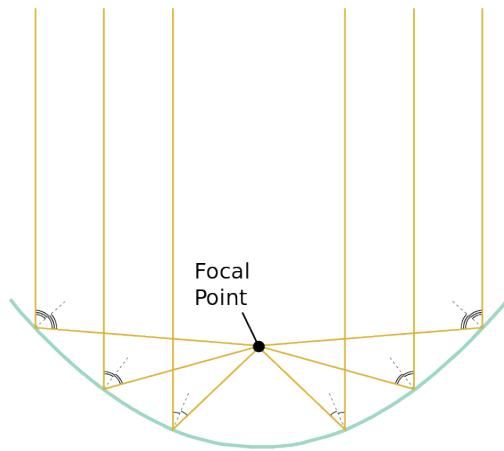


Curved  
TV Screen



Sloth  
Spine

Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ►  
Through the evolution of the shape ► Changing the spatial dimension, from 1D to 2D, up to 3Ds  
► Following the evolution: linear, planar, curved.



Input: Solar Power:  $P_{in}$

$$P_{in} = GA$$

$G$  =Solar heat flux density

$A$  =Frontal area of parabolic collector

Output: Convective Thermal Power:  $P_{out}$

$$P_{out} = \alpha_i A_i (T_w - T_f)$$

$\alpha_i$  =Convection coefficient

$A_i$  =Convection coefficient

$T$  =Temperature (w= wall, f=flow)

Internal: Energy balance of the manifold

$$P_{in} + \alpha_e A_e (T_a - T_w) + \sigma \varepsilon A_e F (T_{sky}^4 - T_w^4) - P_{out} = 0$$

$\alpha_e$  =Convection coefficient

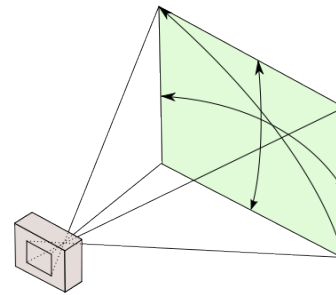
$\sigma$  =Stefan Boltzmann constant

$\varepsilon$  =Emissivity

$A_e$  =External area of the tubular manifold

$F$  =Area fraction

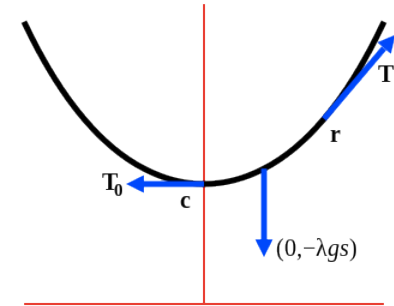
$T$  =Temperature (w=wall, a=air, sky=sky)



### Viewing angle

$$\phi W_c = \tan^{-1} \left( \frac{L \times \sin(X) + \frac{W_c}{2}}{L \times \cos(X) - \Delta D} \right) - \tan^{-1} \left( \frac{L \times \sin(X) - \frac{W_c}{2}}{L \times \cos(X) - \Delta D} \right)$$

Here,  $L$  is a view distance,  $X$  is a view angle,  $\Delta D$  is a length between the front and the rear of the display plane before and after the display plane is curved,  $W$  is a horizontal width of the display panel before the display panel is curved, and  $W_c$  is a horizontal width of the display panel after the display panel is curved.



By RDBury (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

This diagram of forces acting on a segment of a catenary from  $c$  to  $r$  simplifies the tension acting on the sloth spine. The forces are the tension  $T_0$  at  $c$ , the tension  $T$  at  $r$ , and the weight of the chain, in this case the spine,  $(0, -\lambda gs)$ . Assuming the chain is at rest the sum of these forces must be zero.

First, let  $T=T(s)$  be the force of tension as a function of  $s$ . Since tension is defined as the force that the string exerts on itself,  $T$  must be parallel to the chain. In other words,

$$T = T u$$

where  $T$  is the magnitude of  $T$  and  $u$  is the unit tangent vector.

Second, let  $G=G(s)$  be the external force per unit length acting on a small segment of a chain as a function of  $s$ . The forces acting on the segment of the chain between  $s$  and  $s+\Delta s$  are the force of tension  $T(s+\Delta s)$  at one end of the segment, the nearly opposite force  $-T(s)$  at the other end, and the external force acting on the segment which is approximately  $G\Delta s$ . These forces must balance so

$$T = (s + \Delta s) \cdot T(s) + G \Delta(s) \approx 0$$

Divide by  $\Delta s$  and take the limit as  $\Delta s \rightarrow 0$  to obtain

$$\frac{dT}{ds} - G = 0$$



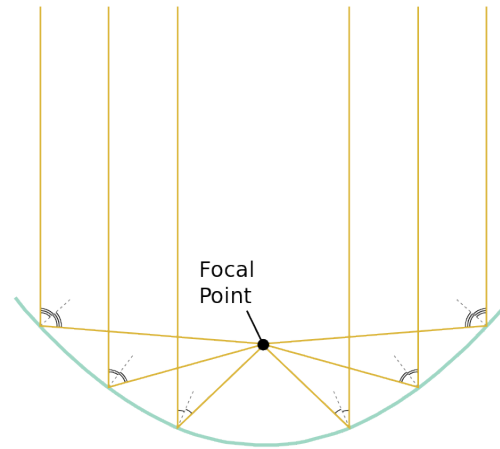
Act on the problem ► By acting on the generation/transmission/interaction systems ► Adapting components ►  
Through the evolution of the shape ► Changing the spatial dimension, from 1D to 2D, up to 3Ds  
► Following the evolution: linear, planar, curved.



Two-toed sloths are unusual among mammals in possessing as few as five cervical vertebrae, which may be due to mutations in the homeotic genes. All other mammals have seven cervical vertebrae.

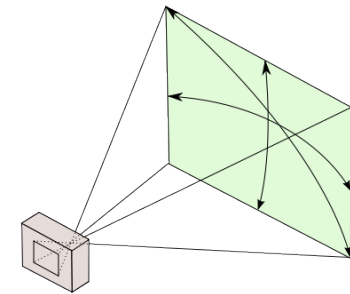
The sloth spends most of its life hanging upside-down from branches. Its skeleton therefore has to cope with tension rather than compression. Consequently, the lumbar bones are reinforced in order to withstand the tension, and it has in general a curved shape.

When the sloth leaves its tree, its belly drags on the ground, because its curved spine is designed to support its body weight from below, not from above, and its legs are too weak to support it



A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal mirror. The energy of sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line, where objects are positioned that are intended to be heated.

There is often a tube, frequently a Dewar tube, which runs the length of the trough at its focal line. The mirror is oriented so that sunlight which it reflects is concentrated on the tube, which contains a fluid which is heated to a high temperature by the energy of the sunlight. The hot fluid can be used for many purposes. Often, it is piped to a heat engine, which uses the heat energy to drive machinery or to generate electricity. This solar energy collector is the most common and best known type of parabolic trough.



Similar to a movie theater having good and bad seats, there is an optimal position when it comes to watching TV at home. This optimal position is directly along the central axis of the TV with the central point of the screen at eye level. Viewers seated in any other position come to experience degradations in picture quality ranging anywhere from minor to severe, the most notable being trapezoidal distortion..

Manufacturers suggest that curved screens allow greater range in satisfactory viewing angles and offer minimal trapezoidal distortion compared to flat-screens.

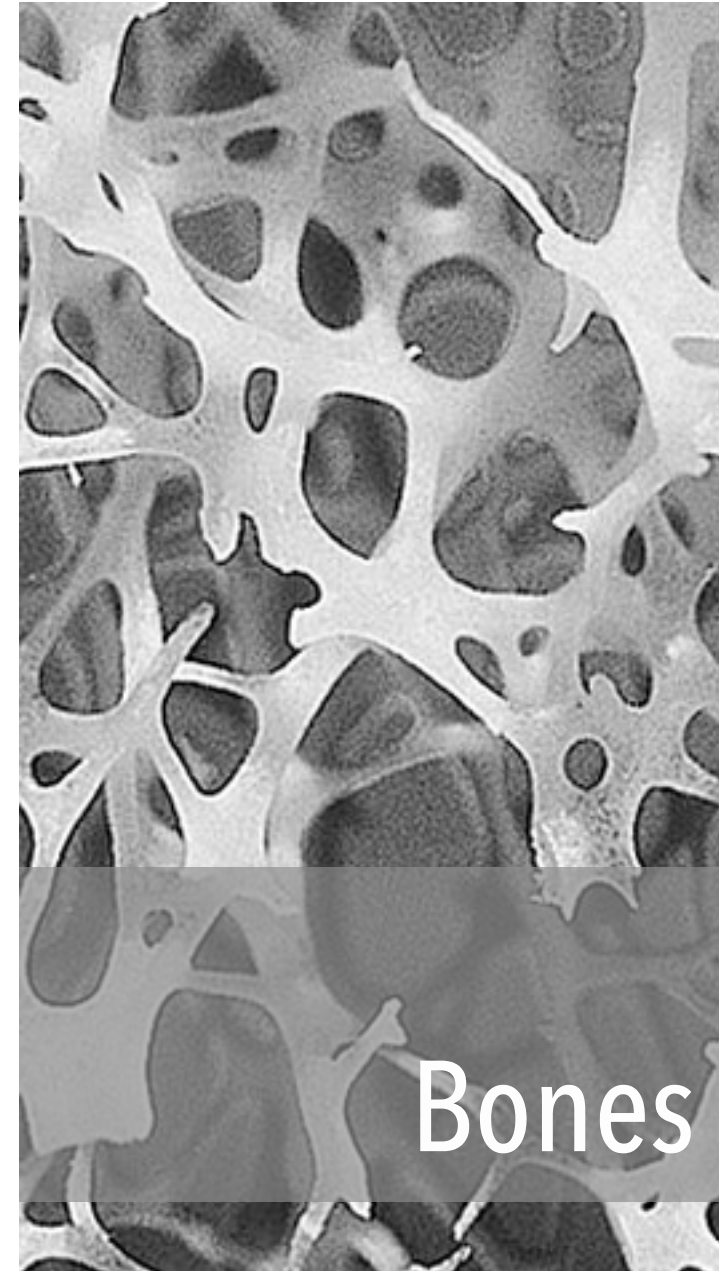
Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally  
Through the adaptation of components ► Through the evolution of materials ► Using their differentiating properties  
(Isotropic/Anisotropic)



Composite  
Materials



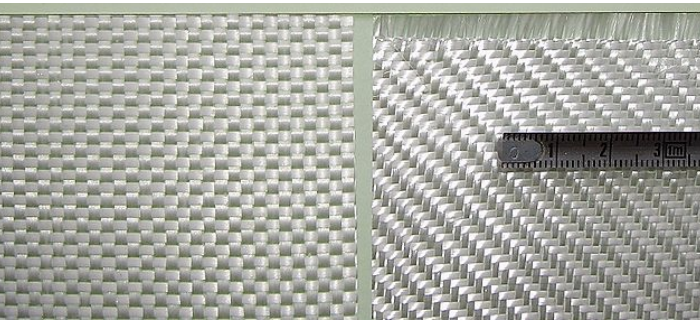
Wooden  
Bike



Bones



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally  
Through the adaptation of components ► Through the evolution of materials ► Using their differentiating properties  
(Isotropic/Anisotropic)



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The physical properties of composite materials are generally not isotropic (independent of direction of applied force) in nature, but rather are typically anisotropic (different depending on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments.

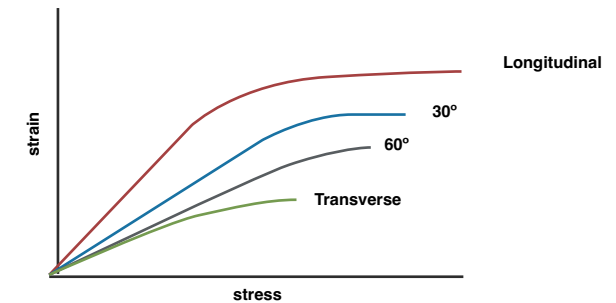
Techniques that take advantage of the anisotropic properties of the materials include mortise and tenon joints (in natural composites such as wood) and Pi Joints in synthetic composites.



Wood has extreme anisotropy because 90 to 95% of all the cells are elongated and vertical (i.e. aligned parallel to the tree trunk). The remaining 5 to 10% of cells are arranged in radial directions, with no cells at all aligned tangentially.

This, in addition to recent technological advances in adhesives and fabrication processes, makes wood an interesting material to explore for the construction of bicycle frames and parts.

The key to designing a wooden bike is to take advantage of the differentiating properties of the material, and make sure its anisotropy becomes strategic in stress and fatigue management.

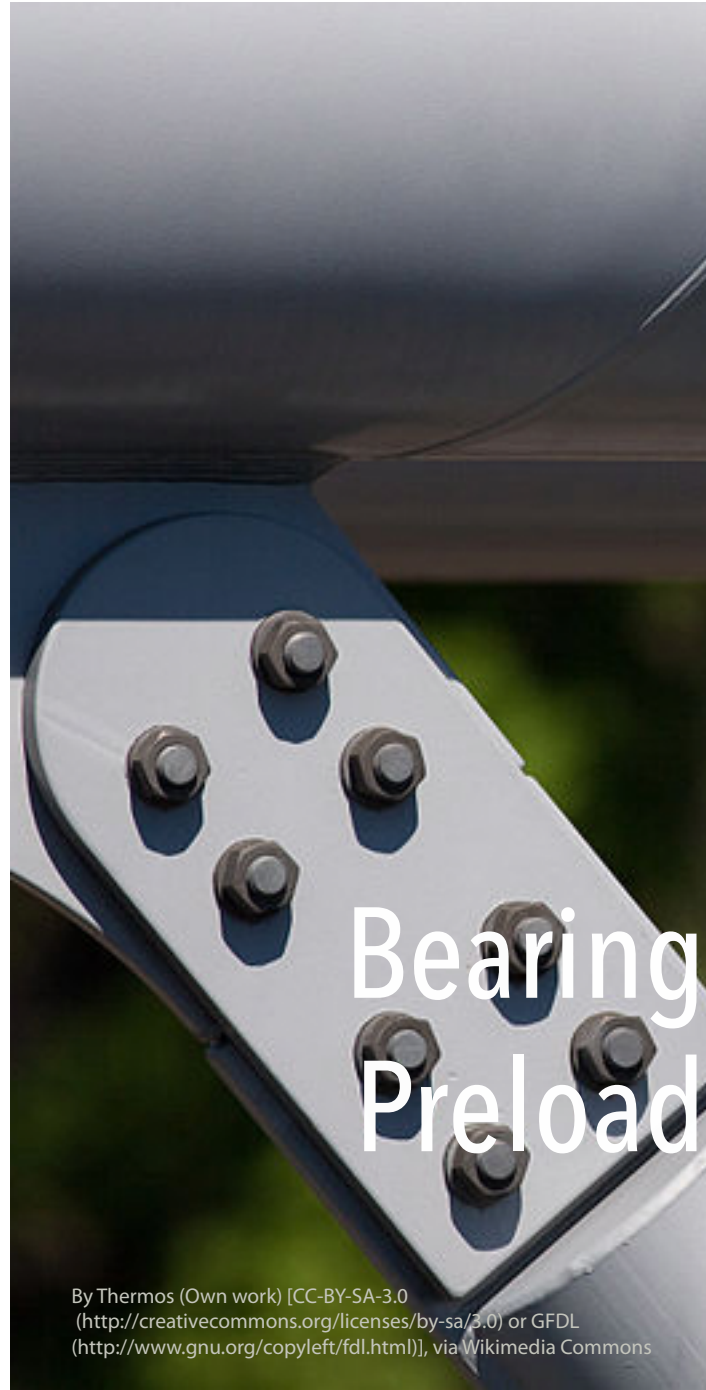
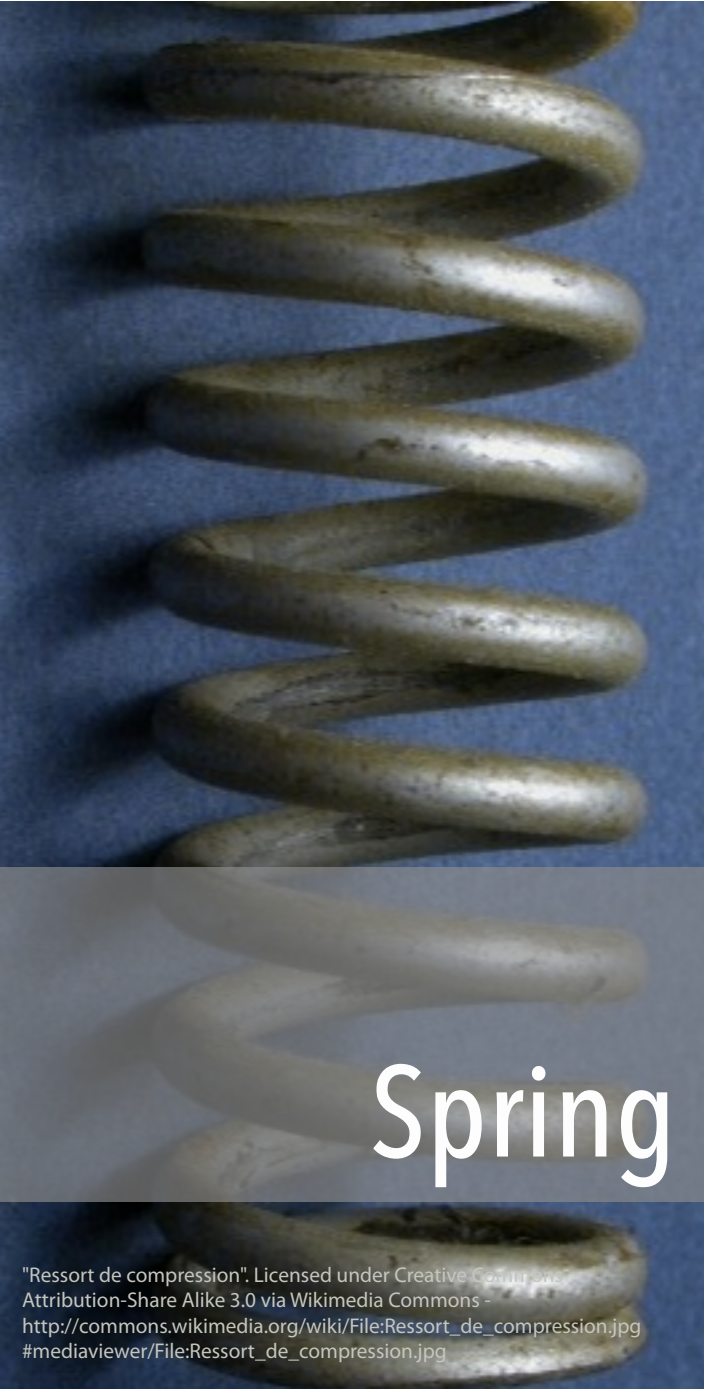


Bone tissue is an anisotropic material, indicating that the bone behavior will change depending on the direction of the load application. In general, the bone tissue may lead to higher loads in the longitudinal direction and a lesser quantity of load when applied over the bone surface. The bone is strong to support loads in the longitudinal direction because it is used to receive loads in this direction.

The bone is also viscoelastic, which means that it responds differently depending on the speed to which the load is applied and the length of the load.

The skeletal system is subjected to a variety of different types of forces on such a way that the bone receives loads in different directions. There are loads produced by the weight sustentation, by the gravity, by muscle forces and by external forces. The loads are applied in different directions producing forces that may vary from five different types: compression, tension, shear, curvature or torsion.

Act on the problem ► By acting on the flow ► Through the introduction of a previous, opposite action to eliminate or compensate the unwanted effects ► Though a preloading system.

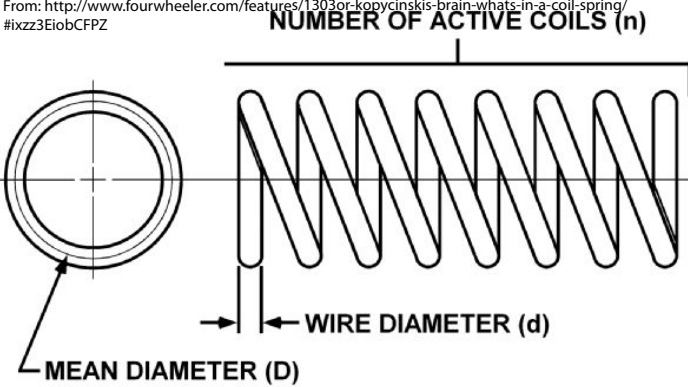




Act on the problem ► By acting on the flow ► Through the introduction of a previous, opposite action to eliminate or compensate the unwanted effects ► Though a preloading system.

Kopycinski's Brain - What's In A Coil Spring?

From: <http://www.fourwheeler.com/features/1303or-kopycinskis-brain-whats-in-a-coil-spring/>  
#ixzz3EiobCFPZ



A spring is an elastic object used to store mechanical energy.

In classical physics, a spring can be seen as a device that stores potential energy, specifically elastic potential energy, by straining the bonds between the atoms of an elastic material.

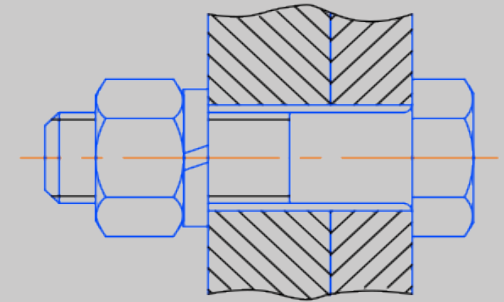
When a coil spring is compressed or stretched slightly from rest, the force it exerts is approximately proportional to its change in length (this approximation breaks down for larger deflections). The rate or spring constant of a spring is the change in the force it exerts, divided by the change in deflection of the spring. That is, it is the gradient of the force versus deflection curve. An extension or compression spring has units of force divided by distance, for example lbf/in or N/m. Torsion springs have units of torque divided by angle, such as N·m/rad or ft·lbf/degree.



By Bjørn Christian Tørrissen [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)], via Wikimedia Commons

Geckos seem to defy gravity as they run along smooth vertical surfaces at up to 20 body lengths per second and even upside down on the ceiling. In general, the principle behind the incredible adhesive ability of geckos is due to the effect of van der Waals forces between their feet and the surfaces they interact with

But, at a more detailed level, this is achieved due to the fact that gecko setae (tiny structures in the foot) apply a preload in the normal axis for adhesion. As a matter of fact, the structure of individual setae and spatulae is such that a small preload and rearward displacement is necessary to engage adhesion. In their resting state, setal stalks are recurved proximally. When the toes of the gecko are planted, the setae are bent out of this resting state, flattening the stalks between the toe and the substrate such that their tips point distally. This small preload and a micron-scale displacement of the toe or scansor proximally may serve to bring the spatulae (previously in a variety of orientations) uniformly flush with the substrate, maximizing their surface area of contact. Adhesion results and the setae are ready to bear the load of the animal's body weight.



Tension bolted joints consist of fasteners that capture and join other parts, and are secured with the mating of screw threads.

The bolt and clamped components of the joint are designed to transfer the external tension load through the joint by way of the clamped components through the design of a proper balance of joint and bolt stiffness. The joint should be designed such that the clamp load is never overcome by the external tension forces acting to separate the joint

The clamp load, also called preload, of a fastener is created when a torque is applied, and so develops a tensile preload that is generally a substantial percentage of the fastener's proof strength.

When a fastener is torqued a tension preload develops in the bolt and a compressive preload develops in the parts being fastened. This can be modeled as a spring-like assembly that has some assumed distribution of compressive strain in the clamped joint components.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally ► Through the segmentation of components ► Into identical elements, hollow elements, by dissociating their functions or interpenetrating them.



Telescopic  
Cylinder



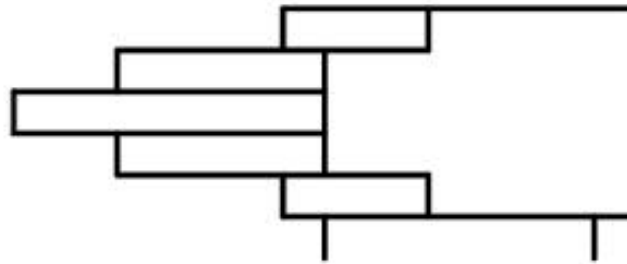
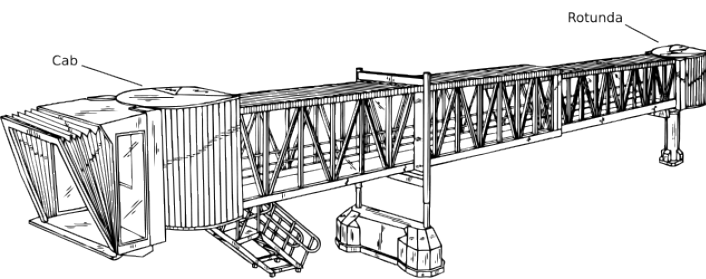
Jet  
Bridge



Scouring  
Horsetail



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally ► Through the segmentation of components ► Into identical elements, hollow elements, by dissociating their functions or interpenetrating them.



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A jet bridge is an enclosed, movable connector which extends from an airport terminal gate to an airplane, allowing passengers to board and disembark without going outside. Depending on building design, sill heights, fueling positions and operational requirements, it may be fixed or movable, swinging radially or extending in length.

By using a retractable tunnel design, loading bridges may retract and extend varying lengths

Telescopic cylinders are a special design of a hydraulic cylinder or pneumatic cylinder which provide an exceptionally long output travel from a very compact retracted length. Typically the collapsed length of a telescopic cylinder is 20 to 40% of the fully extended length depending on the number of stages.

Heavy duty telescopic cylinders are usually powered by hydraulics, whereas some lighter duty units could also be powered by compressed air.

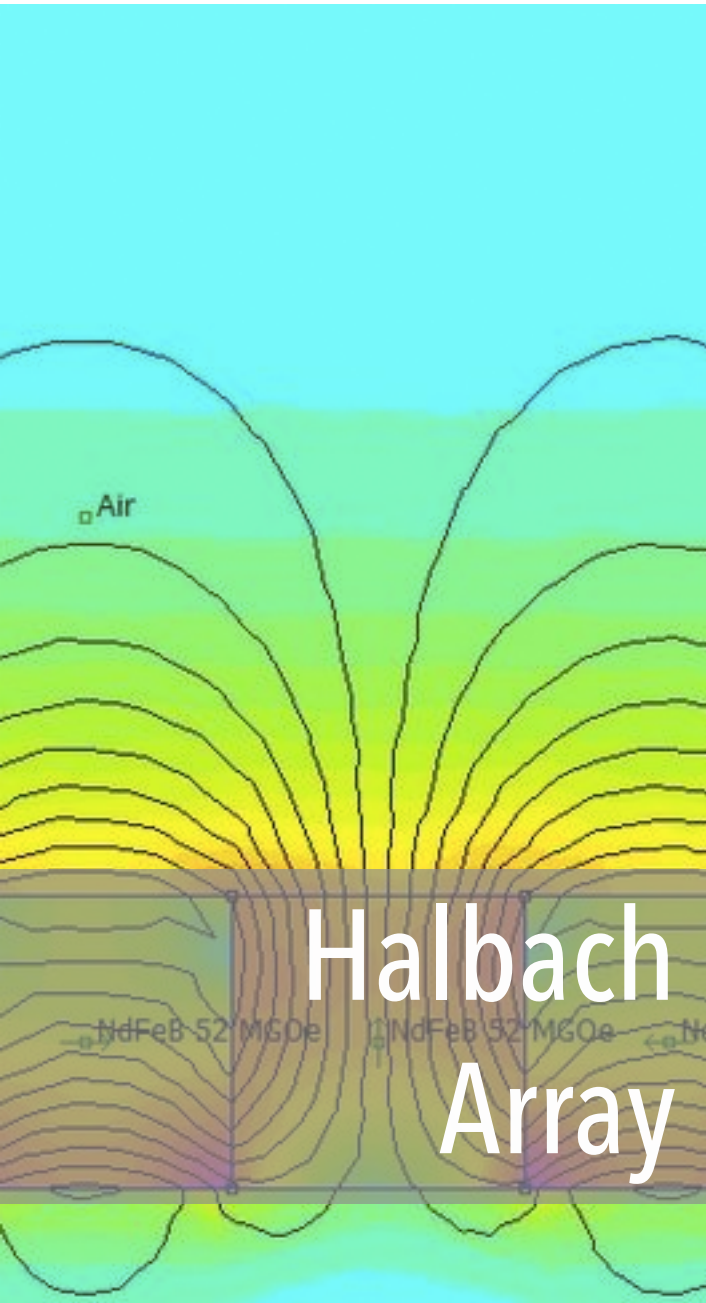
For a given input flow rate, the speed of operation increases in steps as each successive section reaches the end of its stroke. Similarly, for a specific pressure, the load-lifting capacity decreases for each successive section.

The structure of some plants with hollow axes, like horsetails and grasses is characterised by a thin outer ring of strengthening tissue stabilised by a lining of parenchyma cells.

The hollow stems are divided into shorter segments by transverse walls and stem thickenings at the nodes. The nodes significantly reduce the danger of local buckling in these light-weight structures. The stability of these stems depends significantly on the internal pressure (turgor) of the parenchymatous cells.



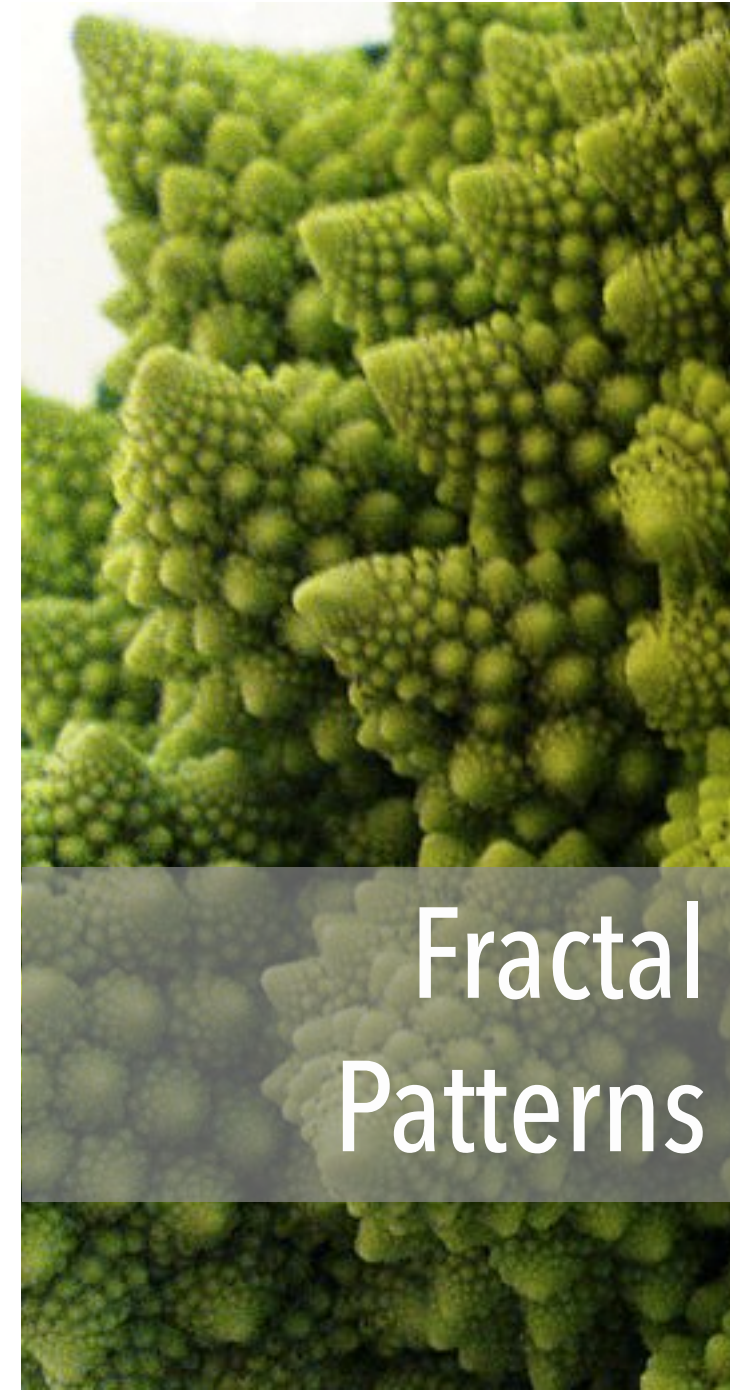
Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally ► Through the segmentation of components ► Into identical components in order to increase effectiveness.



Halbach  
Array

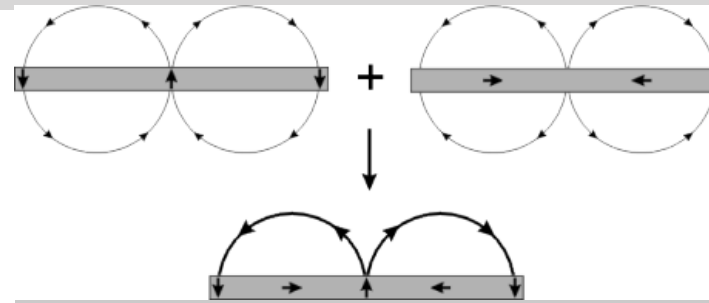
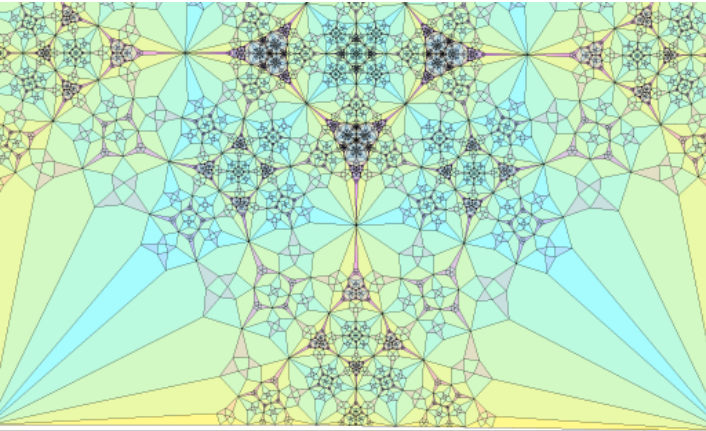


Kipoz Digital  
Ink Board



Fractal  
Patterns

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally ► Through the segmentation of components ► Into identical components in order to increase effectiveness.

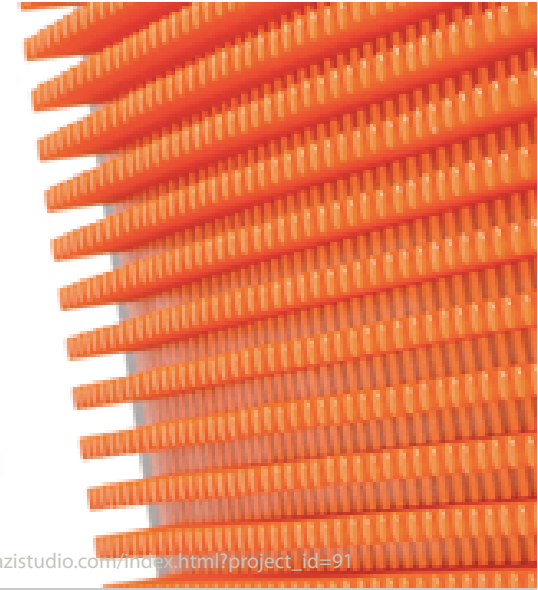


A Halbach array is a special arrangement of permanent magnets that augments the magnetic field on one side of the array while cancelling the field to near zero on the other side. This is achieved by having a spatially rotating pattern of magnetisation.

The rotating pattern of permanent magnets (on the front face; on the left, up, right, down) can be continued indefinitely and have the same effect. The effect of this arrangement is roughly similar to many horseshoe magnets placed adjacent to each other, with similar poles touching. The crucial point is that the flux will cancel below the plane and reinforce itself above the plane.

The advantages of one sided flux distributions are twofold:

- The field is twice as large on the side on which the flux is confined (in the idealised case).
- No stray field is produced (in the ideal case) on the opposite side. This helps with field confinement, usually a problem in the design of magnetic structures.



[http://www.tarazistudio.com/index.html?project\\_id=91](http://www.tarazistudio.com/index.html?project_id=91)

Kipoz is a full color digital ink signage in high resolution, that uses magink's digital ink.

Each unit is supplied as an integrated solution, including sealed housing system with back service. The back side of the billboard is designed to dissipate heat through aluminium fins.

By adding a large number of fins, in the available surface of the back, heat is dissipated more effectively, maintaining the system in optimal conditions during its operation.

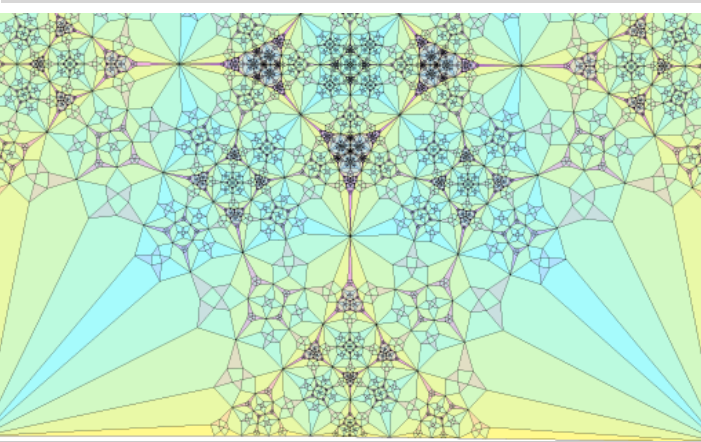
A fractal is a natural phenomenon or a mathematical set that exhibits a repeating pattern that displays at every scale. If the replication is exactly the same at every scale, it is called self-similar pattern. Fractals can also be nearly the same at different levels.

The feature of "self-similarity" is easily understood by analogy to zooming in with a lens or other device that zooms in on digital images to uncover finer, previously invisible, new structure. If this is done on fractals, however, no new detail appears; nothing changes and the same pattern repeats over and over, or for some fractals, nearly the same pattern reappears over and over.

Approximate fractals found in nature display self-similarity over extended, but finite, scale ranges.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Globally ► Through the segmentation of components ► Into identical components in order to increase effectiveness.

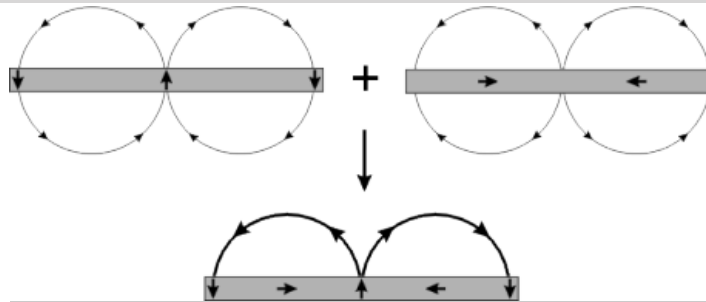


There are numerous mathematical operations that generate fractal patterns when plotted.

The Mandelbrot set, for instance, is the set of values of  $c$  in the complex plane for which the orbit of 0 under iteration of the complex quadratic polynomial

$$z_{n+1} = z_n^2 + c$$

remains bounded. That is, a complex number  $c$  is part of the Mandelbrot set if, when starting with  $z_0 = 0$  and applying the iteration repeatedly, the absolute value of  $z_n$  remains bounded however large  $n$  gets.



The field on the non-cancelling side of the ideal, continuously varying, infinite array is of the form:

$$F(x, y) = F_0 e^{ikx} e^{-ky}$$

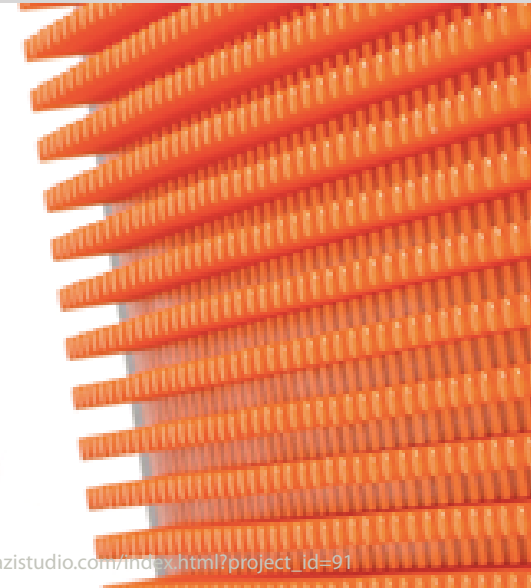
Where:

$F(x, y)$  is the field in the form

$\scriptstyle F_x + i F_y$

$F_0$  is the magnitude of the field at the surface of the array

$k$  is the spatial wavenumber, (i.e., the spatial frequency)



[http://www.tarazistudio.com/index.html?project\\_id=91](http://www.tarazistudio.com/index.html?project_id=91)

## HEAT TRANSFER COEFFICIENT

$$\Delta Q = \alpha \times \mu \times S \times (T - T_m) \times \Delta t$$

where:

$\Delta Q$  = Heat exchange;

$\alpha$  = transfer coefficient;

$\mu$  = Efficiency of the material

$S$  = Area of the contact surface;

$T$  = Temperature of material;

$T_m$  = Temperature of the environment;

$\Delta t$  = Duration.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the flow ► Through the coordination of rhythms ► By increasing the frequency of vibration up to ultrasonic vibrations.



Ultrasonic  
Motor



Sonication



Dolphins  
Echolocation

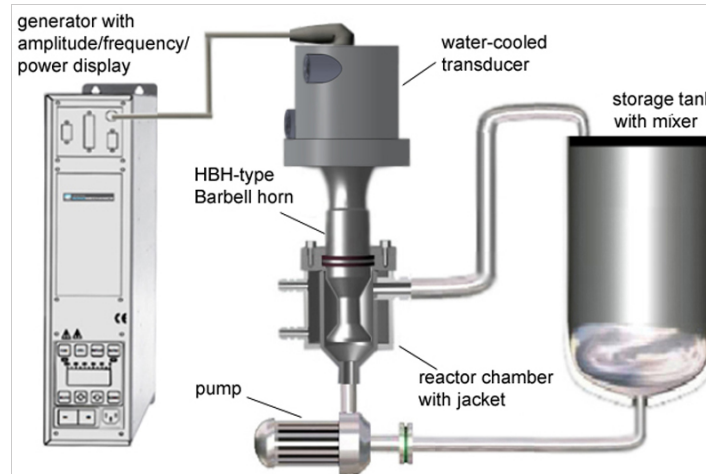


Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the flow ► Through the coordination of rhythms ► By increasing the frequency of vibration up to ultrasonic vibrations.



An ultrasonic motor is a type of electric motor powered by the ultrasonic vibration of a component, the stator, placed against another component, the rotor or slider depending on the scheme of operation (rotation or linear translation).

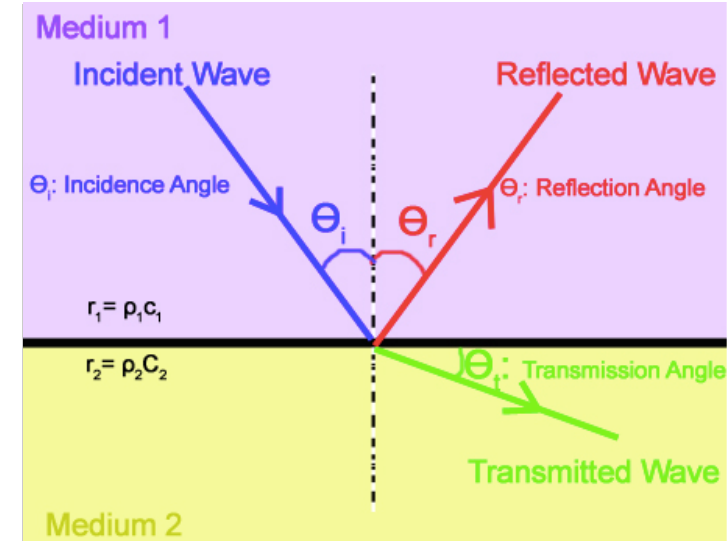
The general principle of the operation of ultrasonic motors is to generate gross mechanical motion through the amplification and repetition of micro-deformations of active material. The active material induces an orbital motion of the stator at the rotor contact points and frictional interface between the rotor and stator rectifies the micro-motion to produce macro-motion of the stator. The active material, which is a piezoelectric material excites a traveling flexural wave within the stator that leads to elliptical motion of the surface particles.



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Sonication is the act of applying sound energy to agitate particles in a sample, for various purposes. Ultrasonic frequencies ( $>20$  kHz) are usually used, leading to the process also being known as ultrasonication or ultra-sonication.

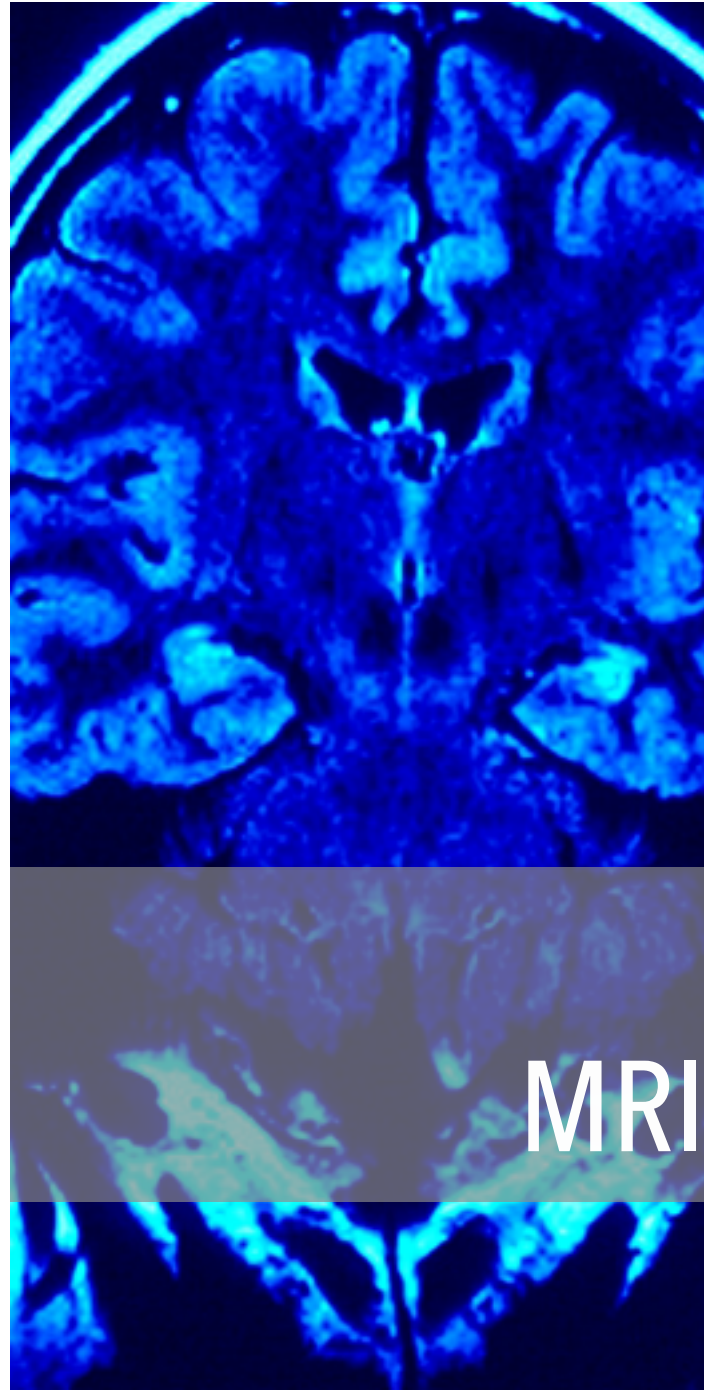
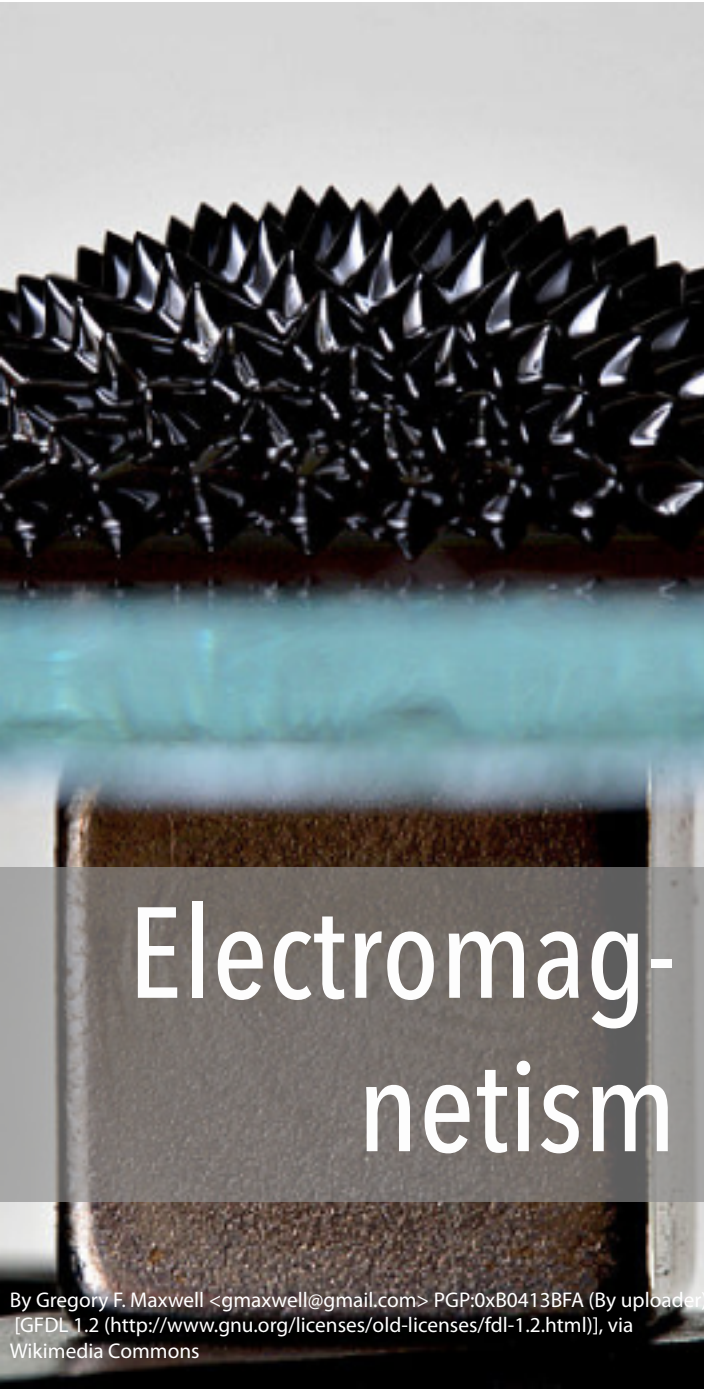
Sonication can be used for the production of nanoparticles, such as nanoemulsions, nanocrystals, liposomes and wax emulsions, as well as for wastewater purification, degassing, extraction of plant oil, production of biofuels, adhesive thinning, and many other processes. It is applied in pharmaceutical, cosmetic, water, food, ink, nanocomposite, and many other industries.



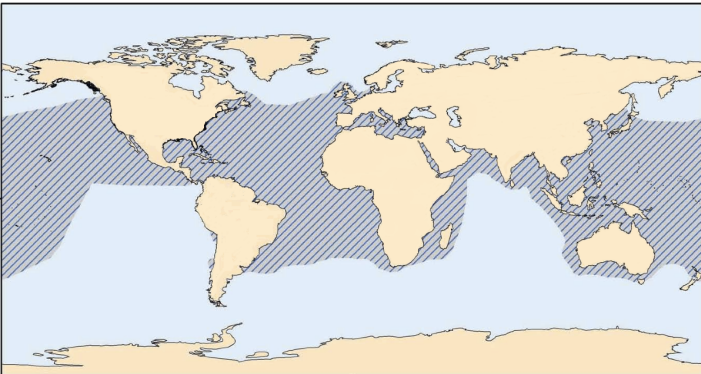
Echolocation is a form of acoustics that uses active sonar to locate objects. Many animals, such as bats and dolphins, use this method to hunt, to avoid predators, and to navigate by emitting sounds and then analyzing the reflected waves. Animals with the ability of echolocation, such as dolphins and bats, rely on multiple receivers to allow a better perception of the objects' distance and direction. By noting a difference in sound level and the delay in arrival time of the reflected sound, these animals determine the location of the object, as well as its size, its density, and other features.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the flow ► Following the MATHEM logic of field evolution ► Through the utilization of a magnetic, electric or electromagnetic field



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the flow ► Following the MATHEM logic of field evolution ► Through the utilization of a magnetic, electric or electromagnetic field

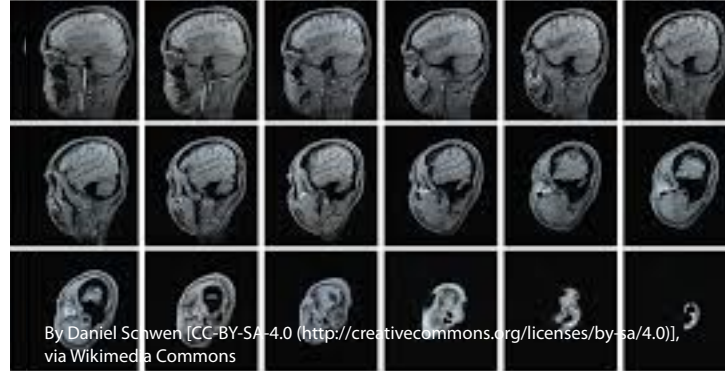


Marine turtles use to return their entire life to the same breeding beach, often located thousands of kilometers off the feeding places, making the return with no visual landmarks.

The turtles' exceptional navigational ability relies on detecting the earth's magnetic field against the deflection induced by the ocean currents. If a powerful magnet attached on the turtles' heads impairs the detection of the Earth's magnetism, the turtles decrease their navigational sense.

They were still able to return to their original egg-laying beach, thus the turtles do not rely only on the geomagnetic field. They probably use olfaction, like some seabirds or homing pigeons do.

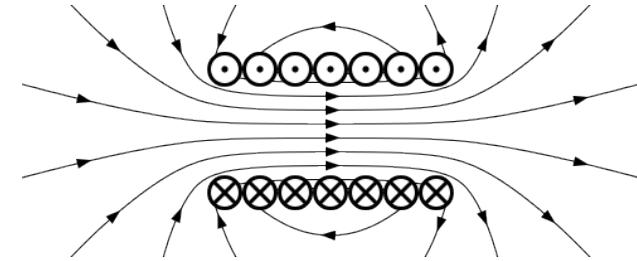
Sea turtles are also known to react to sudden changes in the terrestrial magnetism and to its inclination, too.



By Daniel Schwen [CC-BY-SA-4.0 (<http://creativecommons.org/licenses/by-sa/4.0/>)], via Wikimedia Commons

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to investigate the anatomy and physiology of the body. MRI scanners use strong magnetic fields and radiowaves to form images of the body.

To perform a study, the patient is positioned within an MRI scanner which forms a strong magnetic field around the area to be imaged. Most medical applications rely on detecting a radio frequency signal emitted by excited hydrogen atoms in the body (present in any tissue containing water molecules) using energy from an oscillating magnetic field applied at the appropriate resonant frequency. The orientation of the image is controlled by varying the main magnetic field using gradient coils. As these coils are rapidly switched on and off they create the characteristic repetitive noises of an MRI scan. The contrast between different tissues is determined by the rate at which excited atoms return to the equilibrium state.



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Electromagnetism is one of the four fundamental interactions in nature.

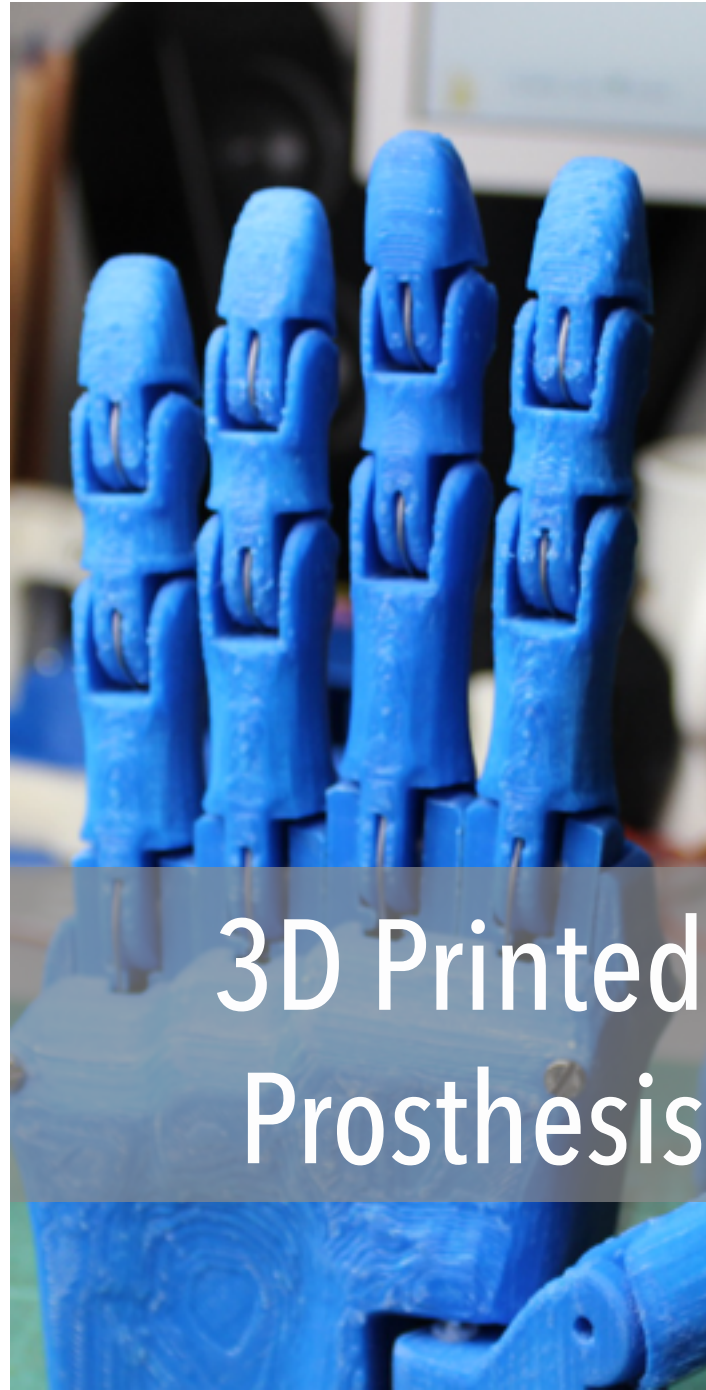
The electromagnetic force is the one responsible for practically all the phenomena one encounters in daily life above the nuclear scale, with the exception of gravity. Roughly speaking, all the forces involved in interactions between atoms can be explained by the electromagnetic force acting on the electrically charged atomic nuclei and electrons inside and around the atoms, together with how these particles carry momentum by their movement. This includes the forces we experience in "pushing" or "pulling" ordinary material objects, which come from the intermolecular forces between the individual molecules in our bodies and those in the objects. It also includes all forms of chemical phenomena.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the materials ► From expensive to inexpensive (or viceversa)



Li-ion  
Batteries



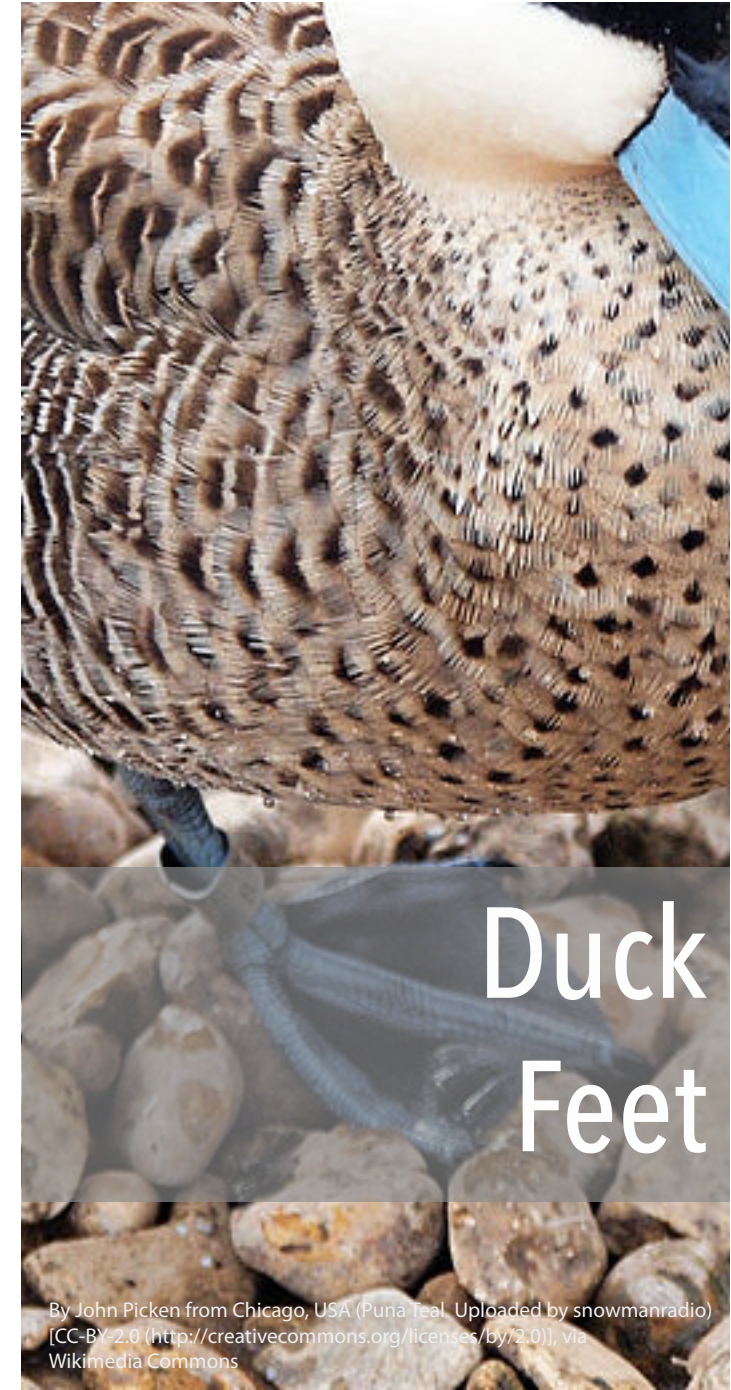
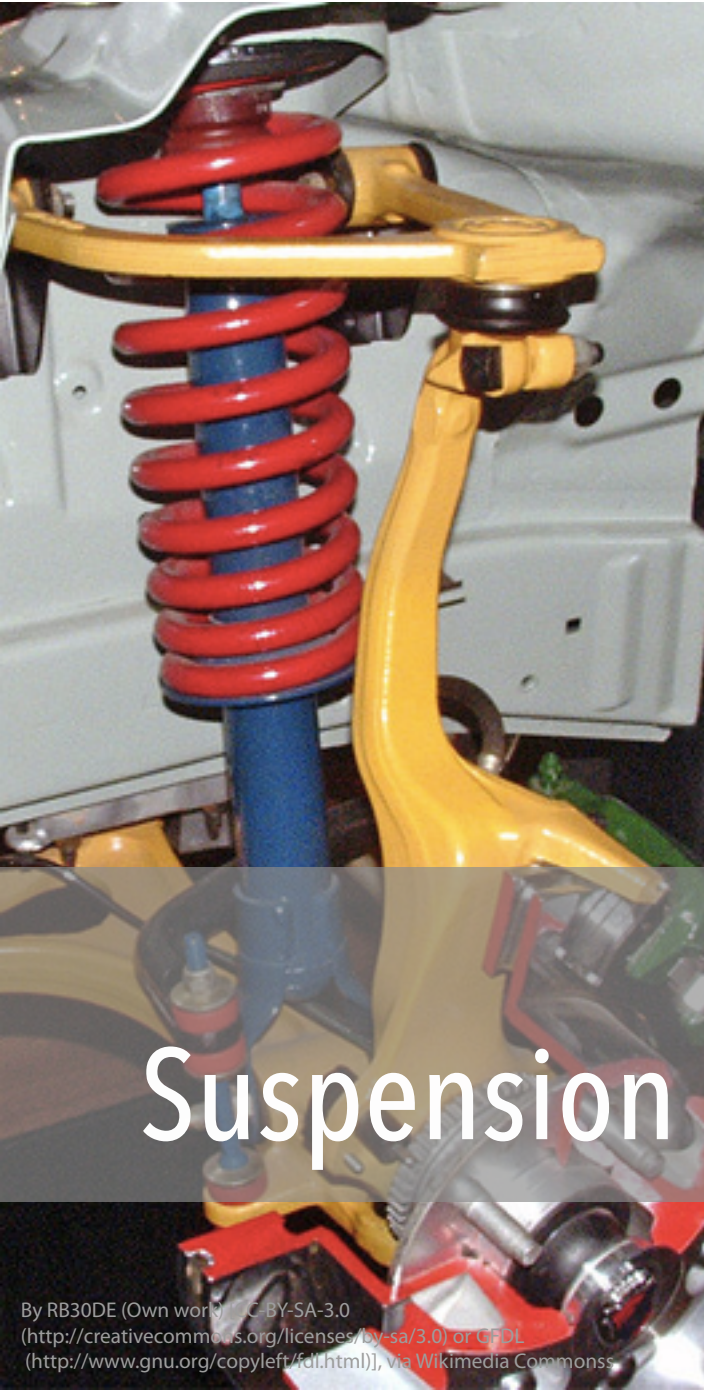
3D Printed  
Prosthesis



Penguins

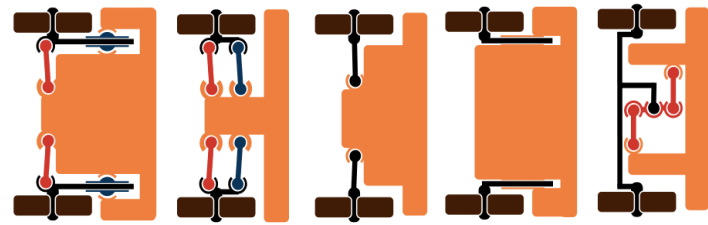


Act on the problem ► By acting on the generation/transmission/interaction systems ► Adding a component ► To divert an undesired action





Act on the problem ► By acting on the generation/transmission/interaction systems ► Adding a component ► To divert an undesired action



Suspension is the system of springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems serve a dual purpose — contributing to the vehicle's roadholding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations, etc.

Springs that are too hard or too soft cause the suspension to become ineffective because they fail to properly isolate the vehicle from the road. Vehicles that commonly experience suspension loads heavier than normal have heavy or hard springs with a spring rate close to the upper limit for that vehicle's weight. This allows the vehicle to perform properly under a heavy load when control is limited by the inertia of the load.

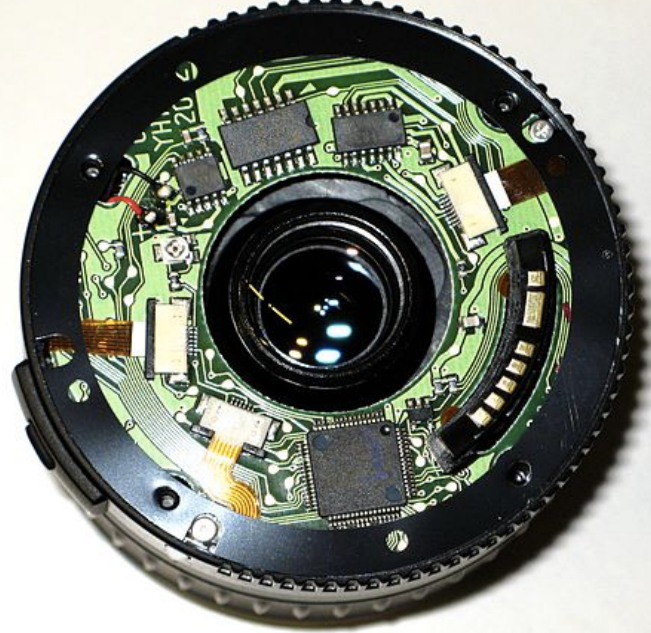


Image stabilization is a family of techniques used to reduce blurring associated with the motion of a camera or other imaging device during exposure. Specifically, it compensates for pan and tilt (angular movement, equivalent to yaw and pitch) of the imaging device.

In photography, image stabilization can often permit the use of shutter speeds 2–4 stops slower (exposures 4–16 times longer).

Image stabilization can be achieved via an external device (tripod), or by mechanisms located in the sensors or lenses of the camera.



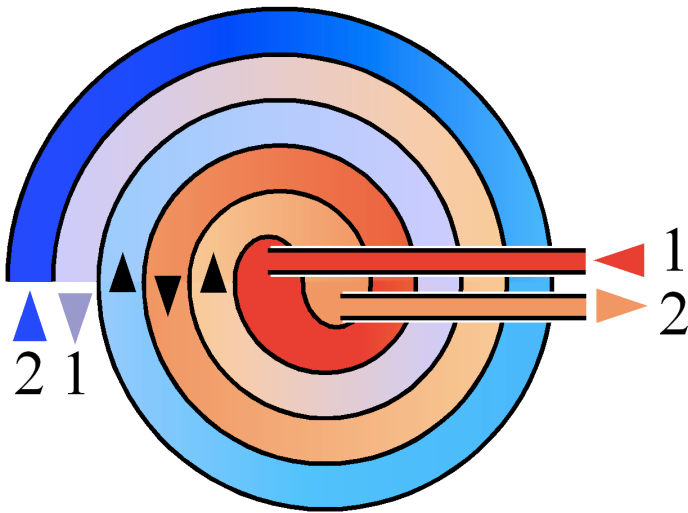
The webbed foot of a duck reduces drag when folded as the foot is brought forward, and provides power when stretched taut and pushed against the water on a backward stroke.

The skin on a duck's foot, though quite leathery, is flexible enough to be folded when the foot is brought forward through the water, causing minimal drag; but it is strong enough to be stretched taut and pushed against the water on the backward stroke. The duck has four toes, arranged like those of most other birds into three forward-pointing toes and one pointing backwards; the forward three toes are joined by a web of skin, but the back toe is free so they can perch

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the shape ► Changing the spatial dimension from 1D to 2D or 3D ► Following the evolution linear-curved-spiral



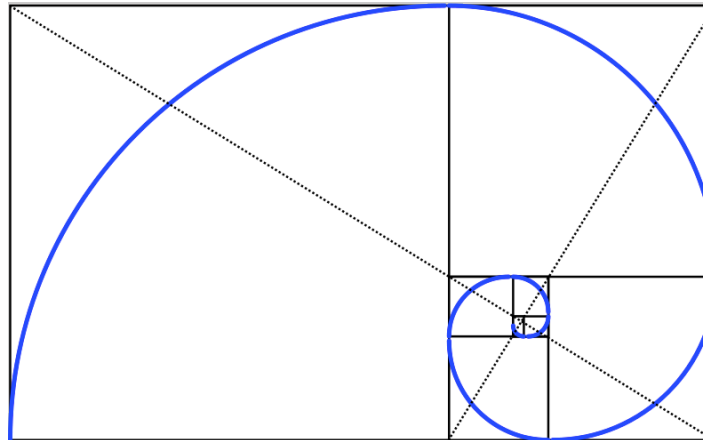
Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the shape ► Changing the spatial dimension from 1D to 2D or 3D ► Following the evolution linear-curved-spiral



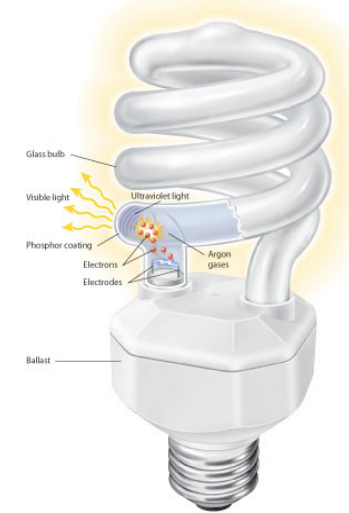
By Michael Schmid (Own work) [GFDL (<http://www.gnu.org/copyleft/fdl.html>), CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or CC-BY-2.5 (<http://creativecommons.org/licenses/by/2.5/>)], via Wikimedia Commons

A spiral heat exchanger (SHE) refers to a pair of flat surfaces that are coiled to form the two channels in a counter-flow arrangement. Each of the two channels has one long curved path. A pair of fluid ports are connected tangentially to the outer arms of the spiral, and axial ports are common, but optional.[15]

The main advantage of the SHE is its highly efficient use of space.



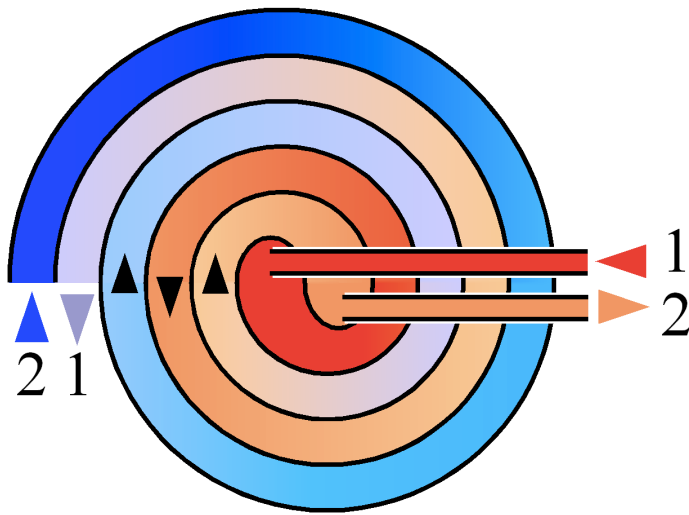
Naturally flowing fluids, gases, and heat follow a common geometric pattern that differs in shape from conventional human-made rotors. Nature moves water and air using a logarithmic or exponentially growing spiral, as commonly seen in sea-shells. This pattern shows up everywhere in Nature: in the curled up trunks of elephants and tails of chameleons, in the pattern of swirling galaxies in outer space and kelp in ocean surf, and in the shape of the cochlea of our inner ears and our own skin pores.



Many people associate CFLs with their unique spiral shape. This spiral pattern is made using machines specifically designed to spin glass. Once the bulb is cool, the air is vacuumed out, and small amounts of mercury gas are added. The spiral shape of these bulbs was built out of necessity. Because fluorescent bulbs produce light only from their phosphorus coating, there needs to be a certain amount of surface area available for this coating. The spiraling glass tube provides the maximum amount of surface space in the smallest total area, which allows the bulb to produce sufficient lighting for most applications.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Through the adaptation of components ► Through the evolution of the shape ► Changing the spatial dimension from 1D to 2D or 3D ► Following the evolution linear-curved-spiral



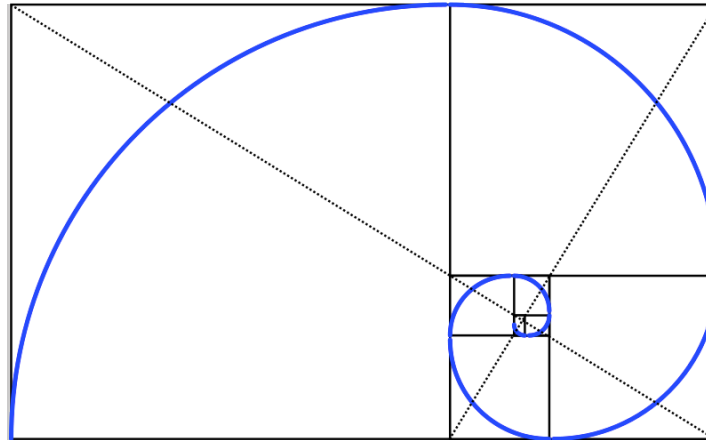
### Log Mean Temperature Difference

The log mean temperature difference is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers. The LMTD is a logarithmic average of the temperature difference between the hot and cold streams at each end of the exchanger. The larger the LMTD, the more heat is transferred.

We assume that a generic heat exchanger has two ends ("A" and "B") at which the hot and cold streams enter or exit on either side; then, the LMTD is defined by the logarithmic mean as follows:

$$LMTD = \frac{\Delta T_A - \Delta T_B}{\ln(\frac{\Delta T_A}{\Delta T_B})}$$

where  $\Delta T_A$  is the temperature difference between the two streams at end A, and  $\Delta T_B$  is the temperature difference between the two streams at end B

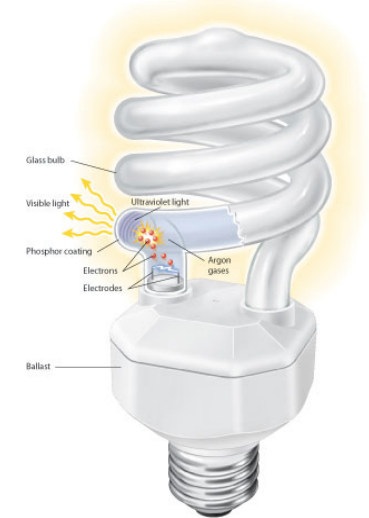


The polar equation for a golden spiral is the same as for other logarithmic spirals, but with a special value of the growth factor b:

$$\theta = \frac{1}{b} \ln(r/a),$$

with e being the base of Natural Logarithms, a being an arbitrary positive real constant, and b such that when  $\theta$  is a right angle (a quarter turn in either direction)

$$e^{b\theta_{right}} = \varphi$$



Intensity can be found by taking the energy density (energy per unit volume) at a point in space and multiplying it by the velocity at which the energy is moving. The resulting vector has the units of power divided by area..

If a point source is radiating energy in all directions (producing a spherical wave), and no energy is absorbed or scattered by the medium, then the intensity decreases in proportion to distance from the object squared

Applying the law of conservation of energy, if the net power emanating is constant,

$$P = \int \mathbf{I} \cdot d\mathbf{A}$$

where P is the net power radiated, I is the intensity as a function of position, and dA is a differential element of a closed surface that contains the source.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Through the modification of components ► Globally ► Through the segmentation of the structure of the components ► Through porous media/ introduction of void



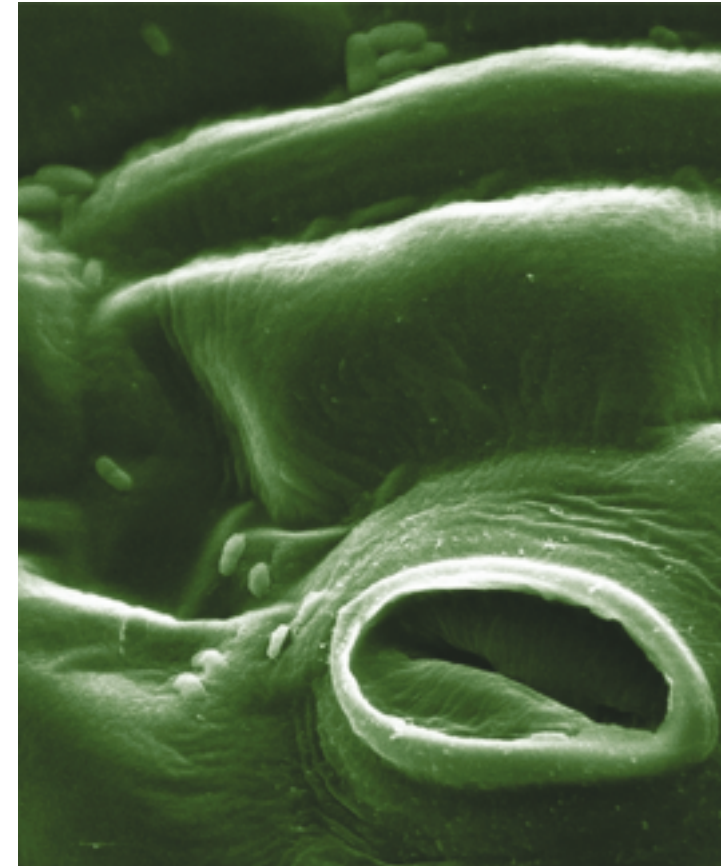
Metal  
Foam

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Gore-Tex

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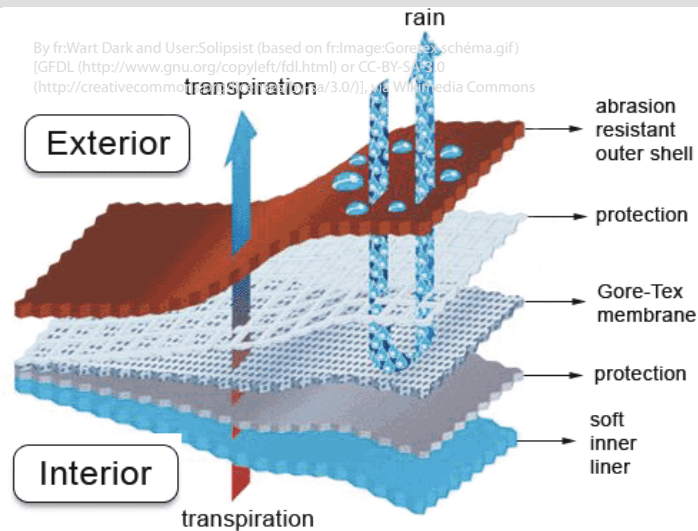


Stomatal  
Pores





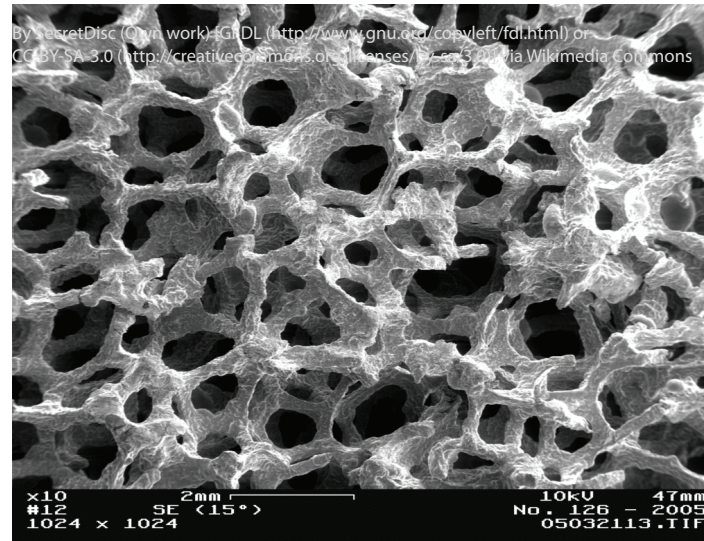
Act on the problem ► By acting on the generation/transmission/interaction systems ► Through the modification of components ► Globally ► Through the segmentation of the structure of the components ► Through porous media/ introduction of void



Gore-Tex is a waterproof, breathable fabric membrane. Invented in 1969, Gore-Tex boasts the ability to repel liquid water while allowing water vapor to pass through, making it a light-weight, waterproof fabric.

Gore-Tex materials are typically based on thermo-mechanically expanded PTFE and other fluoropolymer products. They are used in a wide variety of applications such as high performance fabrics, medical implants, filter media, insulation for wires and cables, gaskets, and sealants. However, Gore-Tex fabric is best known for its use in protective, yet breathable, rainwear.

Gore-Tex is also used internally in medical applications, because it is nearly inert inside the body. In addition, the porosity of Gore-Tex permits the body's own tissue to grow through the material, integrating grafted material into the circulation system. Gore-Tex is used in a wide variety of medical applications, including sutures, vascular grafts, heart patches, and synthetic knee ligaments.

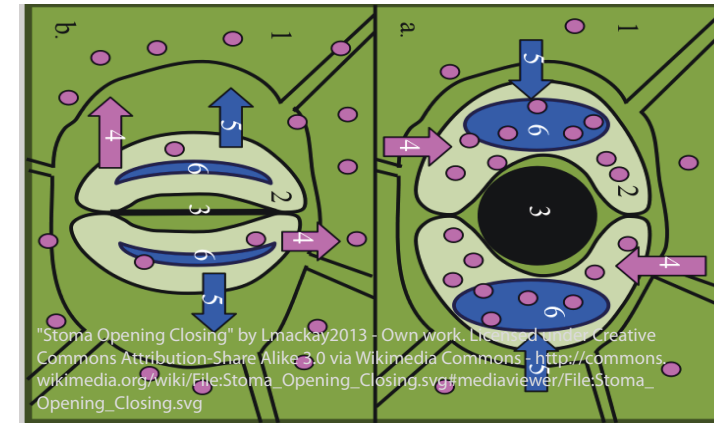


A metal foam is a cellular structure consisting of a solid metal, frequently aluminium, as well as a large volume fraction of gas-filled pores. The pores can be sealed (closed-cell foam), or they can form an interconnected network (open-cell foam).

Open celled metal foams have a wide variety of applications including heat exchangers, energy absorption, flow diffusion and lightweight optics.

Extremely fine-scale open-cell foams, consisting of cells smaller than visible to the naked eye, are used as high-temperature filters in the chemical industry.

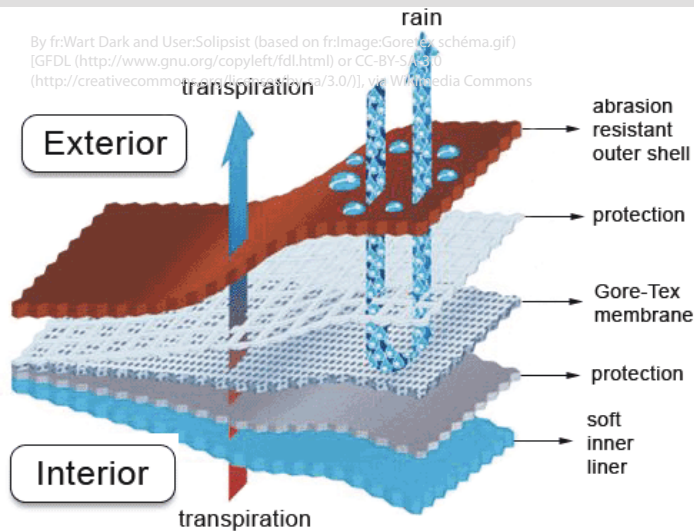
Closed-cell metal foams are primarily used as an impact-absorbing material, similarly to the polymer foams in a bicycle helmet but for higher impact loads. They are light (typically 10–25% of the density of an identical non-porous alloy) and stiff, and are frequently proposed as a lightweight structural material.



In order for plants to produce energy and maintain cellular function, their cells undergo the highly intricate process of photosynthesis. Stomata are located on the outermost cellular layer of leaves, stems, and other plant parts. An open stoma facilitates the process of photosynthesis, but it might derive in water loss. Therefore, a balance must be maintained that allows light and gases to pass between cells, and does not dehydrate the plant.

This problem is mitigated with guard cells, which are a pair of two cells that surround each stoma opening. To open, the cells are triggered by environmental or chemical signals. In response to these signals, the guard cells take in solutes through their membranes. An increase in solutes induces an influx of water across the guard cell membrane. As the volume of the guard cells increase, they “inflate” into two kidney-bean-like shapes. As they expand, they reveal the stoma opening in the center of the two guard cells. Once fully expanded, the stoma is open and gases can move between the cell and external environment.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Through the modification of components ► Globally ► Through the segmentation of the structure of the components ► Through porous media/ introduction of void



The total resistance to the diffusion of water vapor between the upper and lower parts of a porous surface (in this case a Gore-tex sample in contact with ice and a desiccant material) can be calculated through the following equation:

$$R = A(P_{ice} - P_{dry})M$$

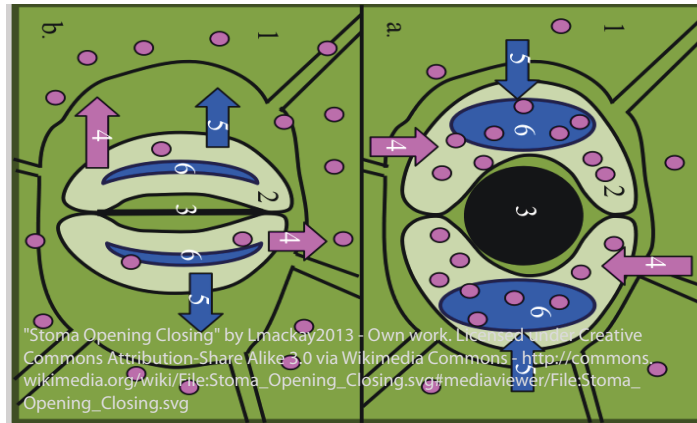
Where:

R= Surface area

P<sub>ice</sub>= Vapor pressure of the ice

P<sub>dry</sub>= Vapor pressure of the desiccant (material that absorbs humidity)

M=Rate of water vapor flow.

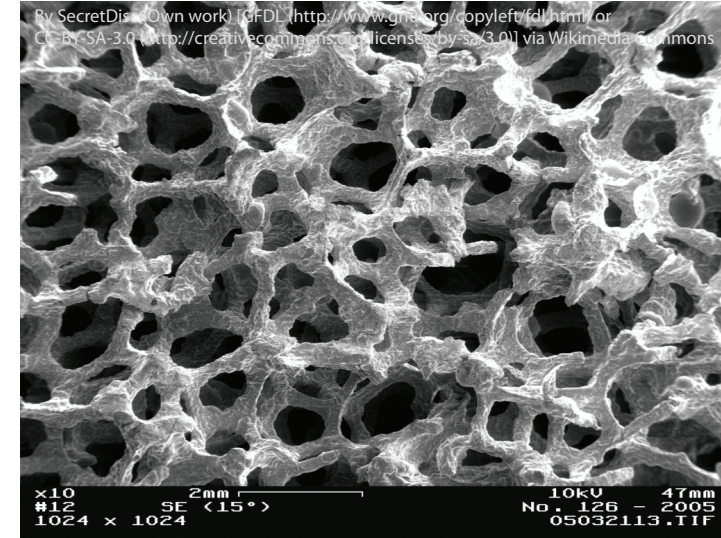


By definition, stomatal conductance, usually measured in  $\text{mmol m}^{-2} \text{s}^{-1}$ , is the measure of the rate of passage of carbon dioxide ( $\text{CO}_2$ ) entering, or water vapor exiting through the stomata of a leaf.

Stomatal conductance with the use of steady-state porometers, which measure stomatal conductance using a sensor head with a fixed diffusion path to the leaf. It measures the vapor concentration at two different locations in the diffusion path. It computes vapor flux from the vapor concentration measurements and the known conductance of the diffusion path using the following equation:

$$\frac{C_{vL} - C_{v1}}{R_{vs} + R_1} = \frac{C_{v1} - C_{v2}}{R_2}$$

Where  $C_{vL}$  is the vapor concentration at the leaf,  $C_{v1}$  and  $C_{v2}$  are the concentrations at the two sensor locations,  $R_{vs}$  is the stomatal resistance, and  $R_1$  and  $R_2$  are the resistances at the two sensors.



Used in geology, hydrogeology, soil science, and building science, the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by the ratio:

$$\phi = \frac{V_v}{V_T}$$

where  $V_v$  is the volume of void-space (such as fluids) and  $V_T$  is the total or bulk volume of material, including the solid and void components.


Porosity is a fraction between 0 and 1, typically ranging from less than 0.01 for solid granite to more than 0.5 for peat and clay. It may also be represented in percent terms by multiplying the fraction by 100.



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► According to CdCF criteria ► Mass

A visualization of topology optimization showing a triangular mesh. The mesh is colored with a gradient from blue to red, indicating stress or strain distribution. A blue line highlights a specific path through the mesh.

# Topology Optimisation

A photograph of a large, modern architectural structure with a complex, tensile design. The structure features a series of interconnected, curved, and ribbed elements that form a large, open space. The design is inspired by natural forms like spider webs or tent structures.

# Tensile Structures

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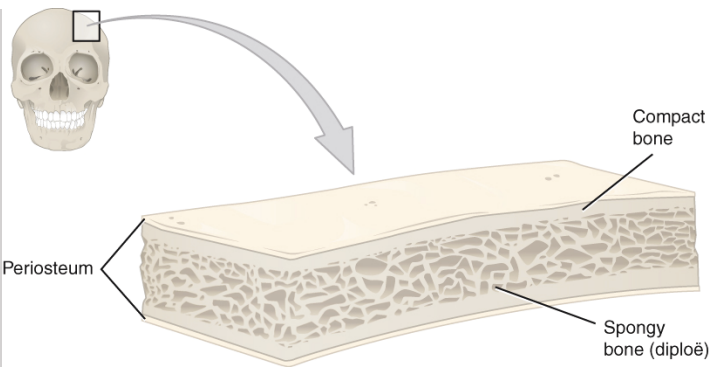
A histological section of spongy bone, showing a complex, porous, and interconnected network of bone tissue. The structure is highly irregular and fractal in nature, with many small, rounded spaces (trabeculae) and a dense, fibrous matrix.

# Spongy Bone Fractal

By Department of Histology, Jagiellonian University Medical  
College (Own work) [CC-BY-SA 3.0 (  
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Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► According to CdCF criteria ► Mass



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A fractal is an object or a structure that is self-similar on all length scales. Fractal patterns are seen in nature at all scales – everything from a single fern leaf that resembles the entire plant, to clouds, snowflakes, blood vessels and cauliflowers shows a fractal pattern. A particular example is trabecular bone – the “spongy” bone that is found near joints in the human body. This bone has a sponge-like network of fibres that have a pseudo-fractal pattern, whereby the pattern is almost self-similar across a few scales. This makes the bone strong but light and capable of providing the necessary strength and stiffness.



By Siemens PLM Software [CC-BY-3.0 (<http://creativecommons.org/licenses/by/3.0/>)], via Flickr

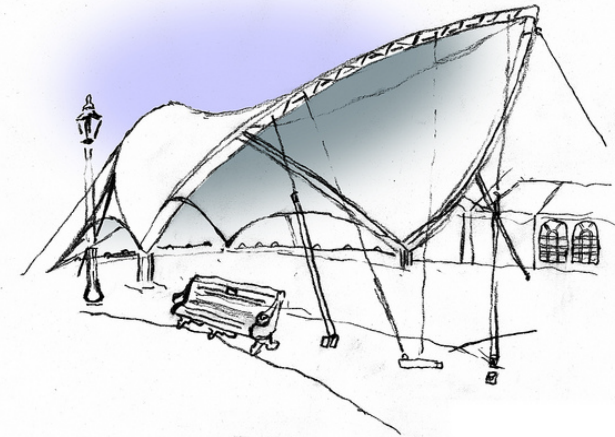
Topology optimisation is a mathematical approach that optimises material layout within a given design space, for a given set of loads and boundary conditions such that the resulting layout meets a prescribed set of performance targets. Using topology optimisation, engineers can find the best concept design that meets the design requirements.

Topology optimisation has been implemented through the use of finite element methods for the analysis, and optimisation techniques based on the method of moving asymptotes, genetic algorithms, optimality criteria method, level sets, and topological derivatives.

Topology optimisation is used at the concept level of the design process to arrive at a conceptual design proposal that is then fine tuned for performance and manufacturability.

With Topology Optimisation a structural shape can be reached that minimizes the amount of material used without compromising its performance.

By Dominic Alves (Own work) CC-BY-SA-2.0 (<http://creativecommons.org/licenses/by-sa/2.0/>) via Flickr



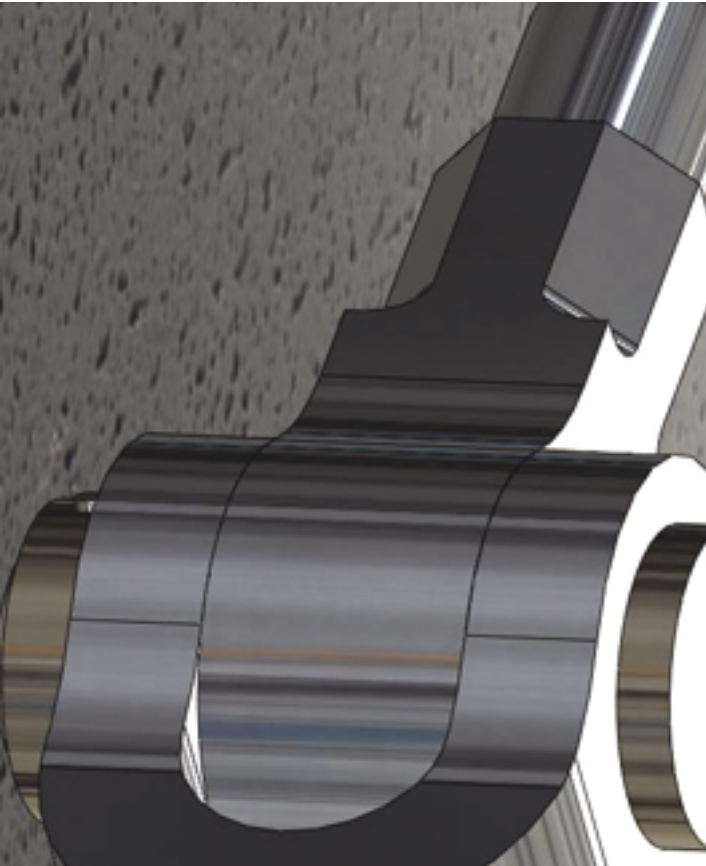
A tensile structure is a construction of elements carrying only tension and no compression or bending.

Most tensile structures are supported by some form of compression or bending elements, such as masts, compression rings or beams.

Common materials for doubly curved fabric structures are PTFE-coated fiberglass and PVC-coated polyester. These are woven materials with different strengths in different directions. The warp fibers can carry greater load than the weft or fill fibers, which are woven between the warp fibers.

One of the clear advantages of tensile structures is the important weight reduction that can be achieved in such large architectural volumes, still accomplishing successfully their initial objective.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the flow ► Dynamizing a component ► Rigid to articulate systems



## Mechanical Joints

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## Campaign Furniture

By Lieutenant Wilmot (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons



## Crustaceans

© Hans Hillewaert / CC-BY-SA-3.0, via Wikimedia Commons

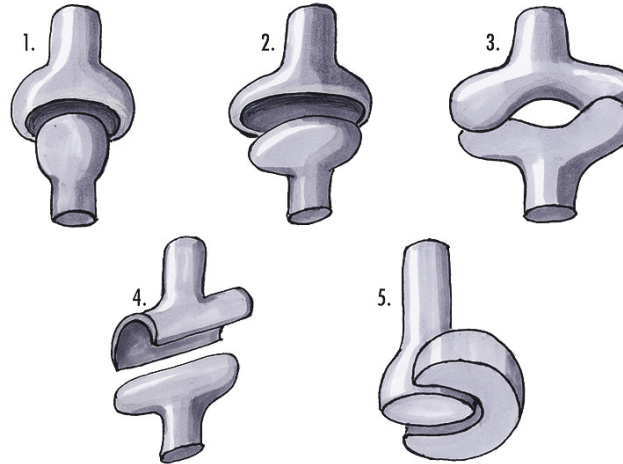
Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the flow ► Dynamizing a component ► Rigid to articulate systems



By Christopher Clark Antiques; <http://campaignfurniture.com/archivesdetailspage.asp?stockNo=8075>

Any furniture specifically made to break-down or fold for ease of travel can be described as campaign furniture. It was designed to be packed up and carried on the march

With campaign furniture by its nature needing to be both sturdy and efficient in its breakdown, it gave rise to good design that was often ahead of its time. A number of chairs that we today consider to be design icons of the 20th century were actually inspired by campaign furniture from the end of the 19th century. The Paragon Chair, depicted here, folds down to a very compact size once the canvas seat is removed and the Harrods catalogue of 1895 described it as "the most Portable Chair in the Market". It is thought that this chair was first designed in the 1870s but it has been re-designed since under different names.

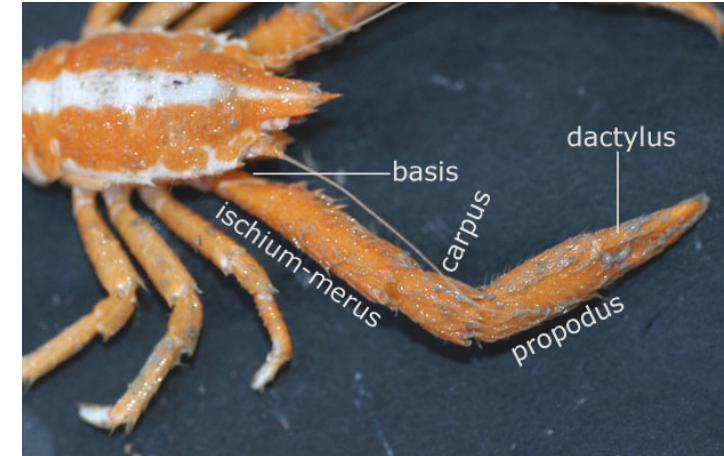


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In order to dynamize a component, the use of mechanical joints is a smart solution. These joints serve to connect components while granting the translation of movement in the whole system.

There are several types of mechanical joints, which usefulness depends on the particular application. Some of the most relevant types are:

- Knuckle joint
- Turnbuckle
- Pin joint
- Bolted joint
- Cotter joint
- Screw joint
- Welded joint



The legs of crustaceans are divided primitively into seven segments

Crustaceans' limbs have an interesting particularity: each joint has two or three articulations, which enables them to rotate in several directions rather than a single plane.

Thanks to this characteristic, crustaceans manage to have a wider range of movements.

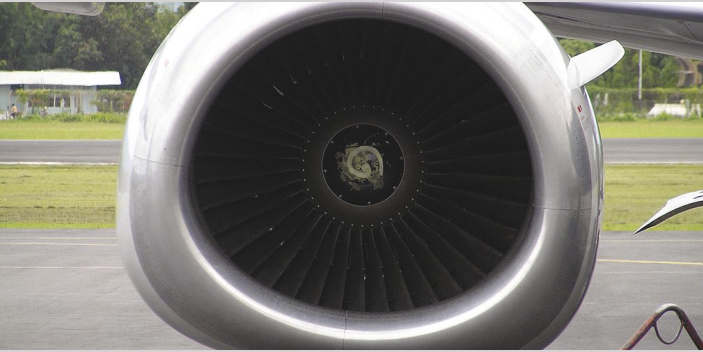


Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► Into an alternative vision ► Symmetric/Asymmetric



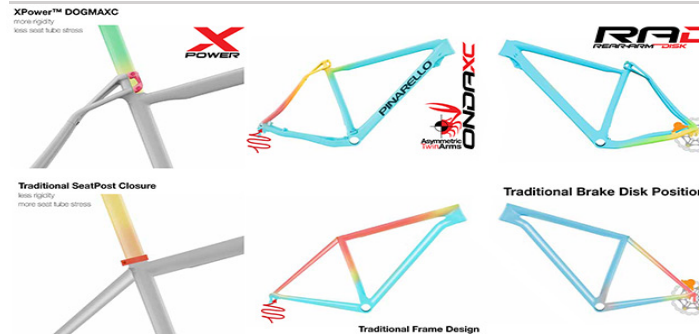


Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► Into an alternative vision ► Symmetric/Asymmetric



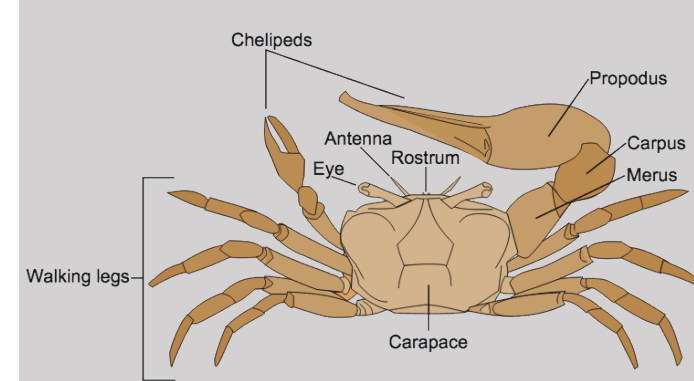
The Boeing B-737 is the only narrow-body airliner in production, with the B-737-600, -700, -800, and -900ER variants being built. The CFM56 turbofan engine was an engineering challenge because of the low ground clearance of the B-737. The problem was solved by placing the engine ahead of (rather than below) the wing, and by moving engine accessories to the sides (rather than the bottom) of the engine pod, giving the B-737 a distinctive non-circular air intake.

The fan diameter was reduced, which reduced the bypass ratio, and the engine accessory gearbox was moved from the bottom of the engine (the 6 o'clock position) to the 9 o'clock position, giving the engine nacelle its distinctive flat-bottomed shape. The overall thrust was also reduced, from 24,000 to 20,000 lbf (107 to 89 kN), mostly due to the reduction in bypass ratio



Pinarello Dogma XC Seat Stay Diagram by Glory Cycles CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>), via Wikimedia Commons

The behavior of a bicycle under pedaling forces is not linear but rather asymmetrical. This is due in most part to pedal forces being applied evenly on both right and left sides (assuming an athlete has a normal and efficient pedal stroke) although the force generated by both right and left is transferred only to the right side of the frame as the chain is located only on the drive side. During part of the pedal stroke forces applied to the bike are opposing and during the other part they are transferred. This, in addition to asymmetric forces being applied to the handlebars as the athlete pushes and pulls even lightly during normal pedaling, creates an input that is not efficient and linear. In other words, pedal forces applied to a symmetric frame can only give an asymmetric and less efficient output. This motivated Pinarello to develop an asymmetrical frame, that would counteract the effects of the asymmetric force exertion on the frame



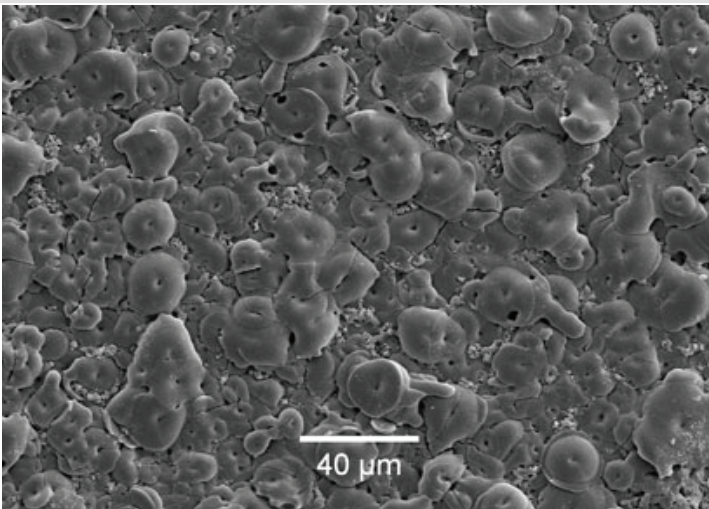
The fiddler crab has evolved two massively different pincers as a way of allowing it to deliver the broadest possible range of functions – one large one for gripping and crushing; and a much smaller one for more delicate manipulations and access to small spaces. During feeding the closing action of the dactyl would be employed for gathering the substrate while other more basal segments of the claw would move the claw to the mouth where the substrate is deposited. These small basal segments would bring about the characteristic waving motion of the major claw during courtship. The closing action of the major claw would be used more in defense e.g., arresting an intruder.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of materials ► Through coatings with different properties



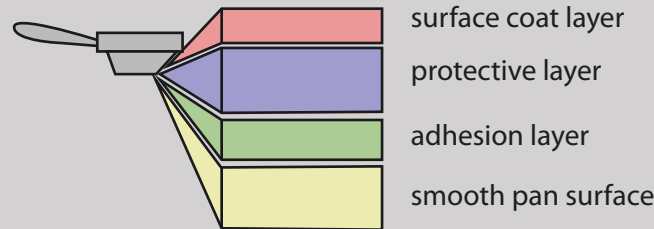


Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of materials ► Through coatings with different properties



By Jac64 (Own work) [CC-BY-SA-2.5 (<http://creativecommons.org/licenses/by-sa/2.5>)

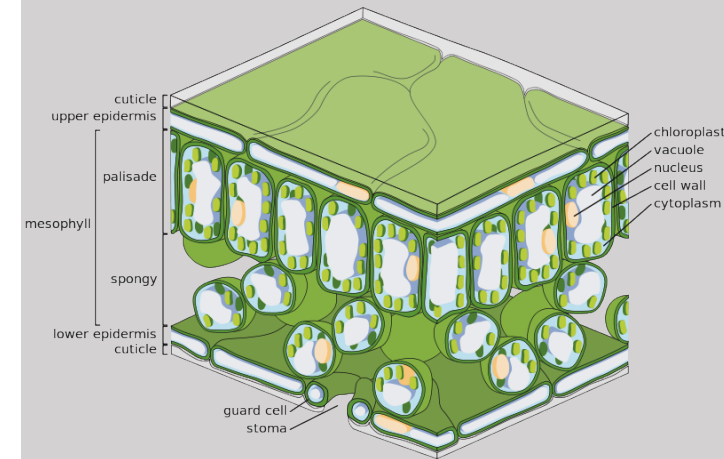
The surface phase of a solid interacts with the surrounding environment. This interaction can degrade the surface phase over time. Environmental degradation of the surface phase over time can be caused by wear, corrosion, fatigue and creep. Surface engineering involves altering the properties of the Surface Phase in order to reduce the degradation over time. This is accomplished by making the surface robust to the environment in which it will be used. A spectrum of topics that represent the diverse nature of the field of surface engineering includes Plating technologies, Nano and emerging technologies and Surface engineering, characterization and testing.



The first non-stick pans were made using a coating of Teflon (polytetrafluoroethylene or PTFE). The substance was found to have several unique properties, including very good corrosion resistance and the lowest coefficient of friction of any substance yet manufactured. PTFE was used first to make seals resistant to the uranium hexafluoride gas used in the Manhattan Project during World War II and was regarded as a military secret. Dupont registered the Teflon trademark in 1944 and soon began planning for post-war commercial use of the new product.

Not all modern non-stick pans use Teflon; other non-stick coatings have become available. For example, a mixture of titanium and ceramic can be sandblasted onto the pan surface, and then fired to 2,000 °C (3,630 °F).

By Zephyris (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)], via Wikimedia Commons

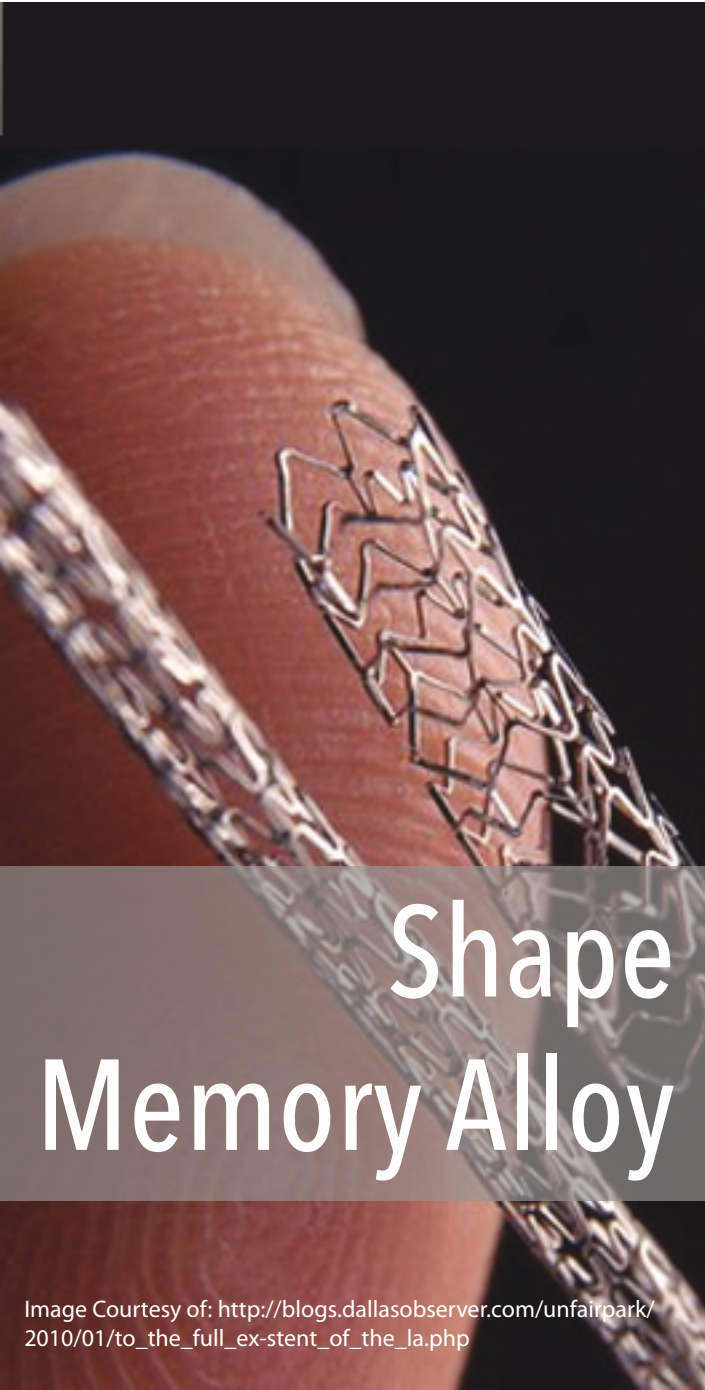


Some trees get rid of plants or other unwanted organisms residing on the surface of their leaves by regularly shedding the waxy coat known as cuticle to their leaves.

It also helps leaves to prevent excess water loss through transpiration. Without this coating they would dry up. The waxy layer blocks the stomata preventing as much water evaporating from them



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► Adapted to the materials ► Using shape memory



Shape  
Memory Alloy



Bose  
Headphones



Fern

By Homer Edward Price (Resurrection-Fern  
Uploaded by Amada44) [CC-BY-2.0 (  
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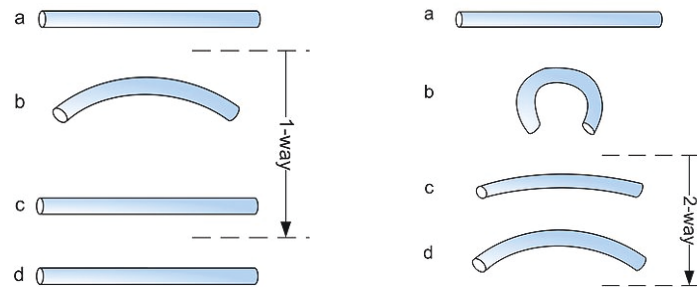


Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► Adapted to the materials ► Using shape memory



The resurrection fern *Polypodium polypodioides* has a remarkable elastic response, where the fast water uptake of the fern upon rehydration is accompanied by a significant reduction in its Young's modulus.

The structure of the resurrection fern is hierarchical, where the smallest elastic units are the plant cells arranged into palisade and spongy layers. Water flows into the layered structures due to capillary pressure, allowing the cells to absorb water as well



By Fongs (Own work) [CC-BY-SA-2.5 (<http://creativecommons.org/licenses/by-sa/2.5>)]

One of the commercial uses of shape-memory alloy exploits the pseudo-elastic properties of the metal during the high-temperature (austenitic) phase. The frames of reading glasses, for example, have been made of shape-memory alloy as they can undergo large deformations in their high-temperature state and then instantly revert to their original shape when the stress is removed.

This is the result of pseudoelasticity; the martensitic phase is generated by stressing the metal in the austenitic state and this martensite phase is capable of large strains. With the removal of the load, the martensite transforms back into the austenite phase and resumes its original shape.

This allows the metal to be bent, twisted and pulled, before reforming its shape when released. This means the frames of shape-memory alloy glasses are claimed to be "nearly indestructible" because it appears no amount of bending results in permanent plastic deformation.

By Johan (Own work) [GFDL (<http://www.gnu.org/copyleft/fdl.html>) or CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)] via Wikimedia Commons



Like many in and on audio devices manufacturers, Bose utilizes memory foam in their headsets and earbuds.

This is due to the fact that higher-density memory foam softens in reaction to body heat, allowing it to mold to a warm body in a few minutes.

Memory foam is made of polyurethane with additional chemicals increasing its viscosity and density. It is often referred to as "viscoelastic" polyurethane foam, or low-resilience polyurethane foam.

Therefore, when wearing earphones that incorporate this technology, the foam will adjust properly to the shape of the ear and give a more comfortable sensation.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of the shape ► Adapted to the materials ► Using shape memory



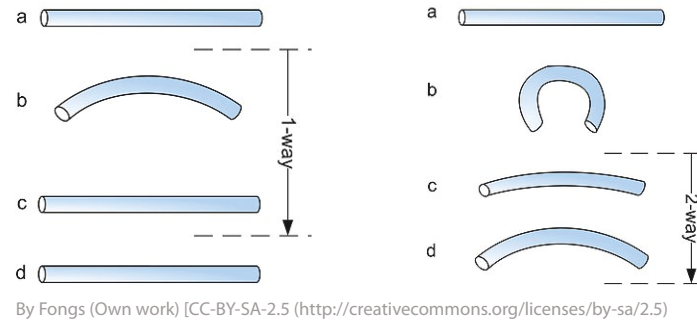
Elasticity is the tendency of solid materials to return to their original shape after being deformed. If the material is elastic, the object will return to its initial shape and size when these forces are removed.

There are various elastic moduli, such as Young's modulus, the shear modulus, and the bulk modulus, all of which are measures of the inherent stiffness of a material as a resistance to deformation under an applied load.

Elasticity is stated as a relationship between stress  $\sigma$  and strain  $\varepsilon$ :

$$\sigma = E\varepsilon$$

where  $E$  is known as the elastic modulus or Young's modulus.

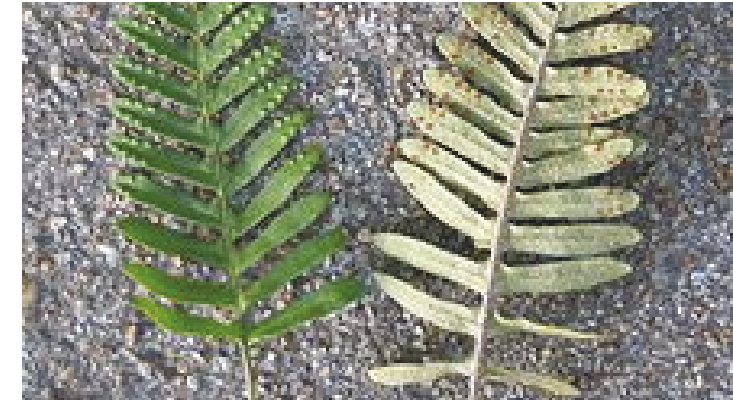


Two important quantities that are used to describe shape-memory effects are the strain recovery rate ( $R_r$ ) and strain fixity rate ( $R_f$ ). The strain recovery rate describes the ability of the material to memorize its permanent shape, while the strain fixity rate describes the ability of switching segments to fix the mechanical deformation.

$$R_r(N) = \frac{\varepsilon_m - \varepsilon_p(N)}{\varepsilon_m - \varepsilon_p(N - 1)}$$

$$R_f(N) = \frac{\varepsilon_p(N)}{\varepsilon_m}$$

where  $N$  is the cycle number,  $\varepsilon_m$  is the maximum strain imposed on the material, and  $\varepsilon_p(N)$  and  $\varepsilon_p(N - 1)$  are the strains of the sample in two successive cycles in the stress-free state before yield stress is applied.



Two important factors are related to the fern's unusual qualities:

### Radius of curvature

$$R(t) = \frac{q(t)^2 + 4h(t)^2}{8h(t)}$$

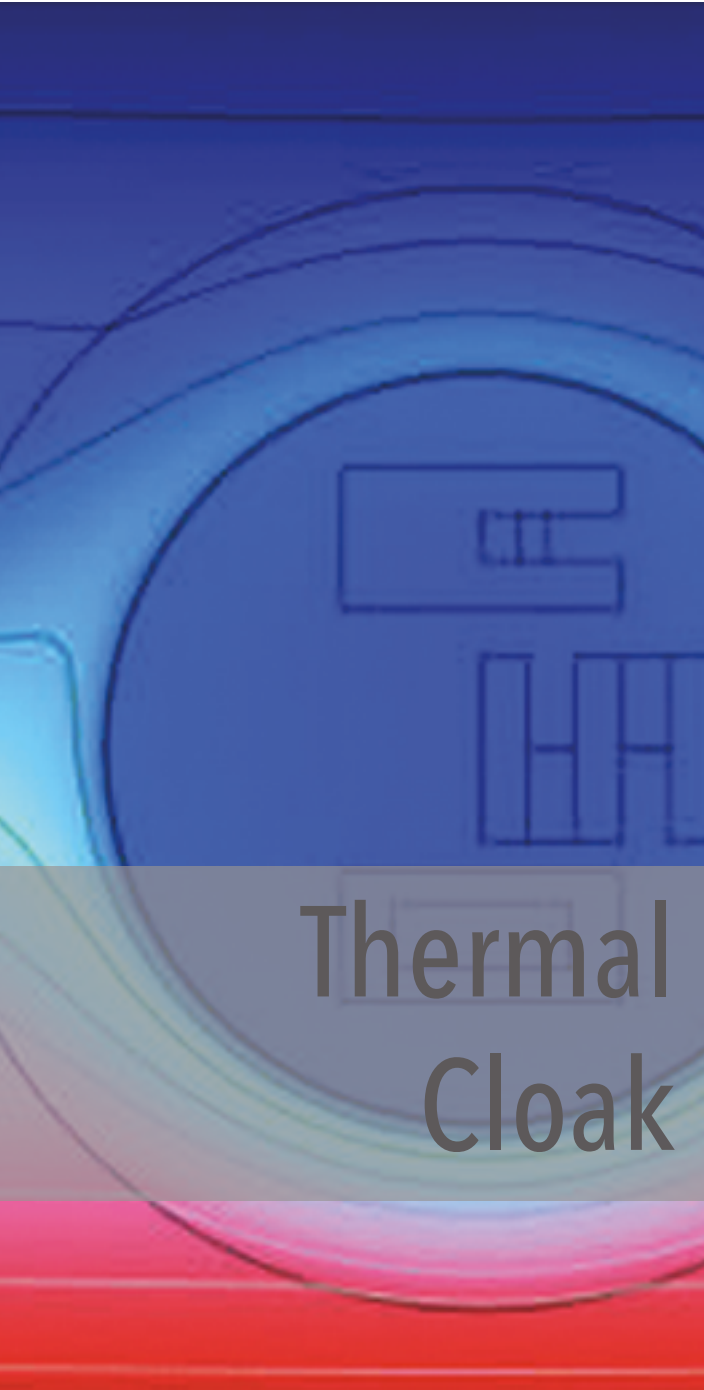
where  $R$  is the radius,  $h$  is the height and  $q$  is the width, all of them functions of time

### Water uptake

$$\frac{dm}{dt} = \phi A_0 \rho_0 v$$

where  $\phi$  is the fraction of air inside the leaf,  $A_0$  is the surface area of the underside,  $\rho$  is the water density inside the leaf and  $v$  is the water velocity.

Act on the problem ► By acting on the flow ► Through the modification of state variables ► Globally



Thermal  
Cloak



LED  
Lightbulbs

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Fan Palm  
Tree

By Mokie (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0>)], via Wikimedia Commons



# Act on the problem ► By acting on the flow ► Through the modification of state variables ► Globally



LED bulbs are more power-efficient than compact fluorescent bulbs and offer lifespans of 30,000 or more hours. However, their benefits can be reduced if operated at a higher temperature than specified.

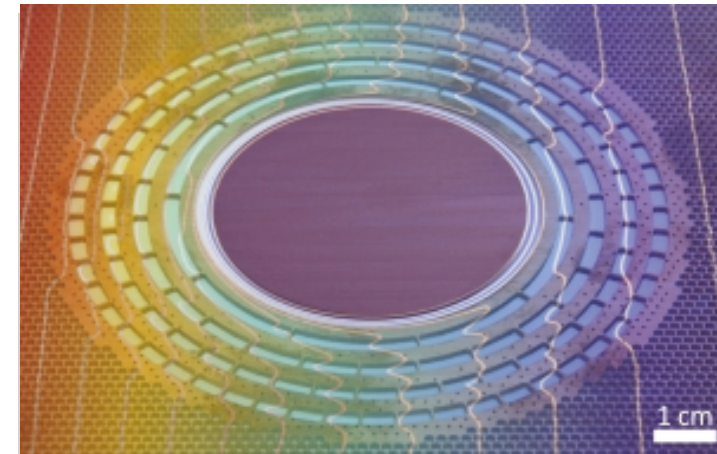
LED performance and lifetime are strongly functions of their temperature. Effective cooling is therefore essential

As a matter of fact, LEDs are adversely affected by high temperature, so LED lamps typically include heat dissipation elements such as heat sinks and cooling fins.



Excessive heating of leaves can seriously damage the chemical structure and the function of biomolecules and, therefore, such high temperatures should be avoided. Nature has consequently developed a series of adaptations, which help leaves control the temperature. One strategy is to keep the heat capacity low by means of building very light leaf structures so that the accumulated heat can easily be transferred to the atmospheric environment. It is also known that the leaf size decreases geographically with increasing solar energy input.

A suitable model plant was found in the fan palm from northeastern Australia. The leaf is cut into segments, which are tilted in such a way that the air can pass freely through the fan transporting off heat.

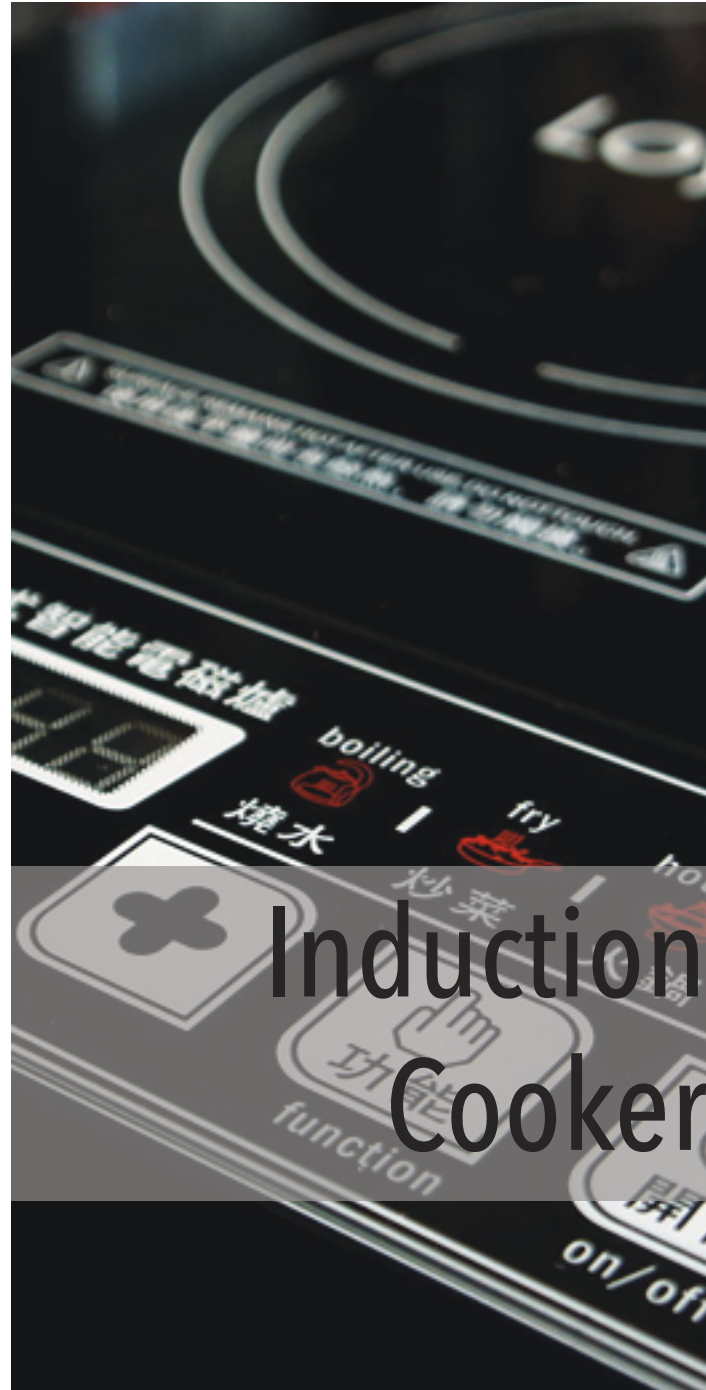


By means of special metamaterials, light and sound can be passed around objects. KIT researchers now succeeded in demonstrating that the same materials can also be used to specifically influence the propagation of heat. A structured plate of copper and silicon conducts heat around a central area without the edge being affected.

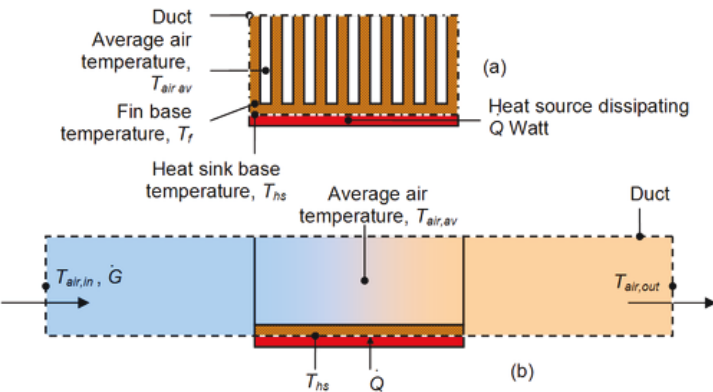
Copper is a good heat conductor, while the silicon material used, called PDMS, is a bad conductor. By providing a thin copper plate with annular silicon structures, the produced material conducts heat in various directions at variable speeds. In this way, the time needed for passing around a hidden object can be compensated.



Act on the problem ► By acting on the flow ► Through the modification of state variables ► Locally



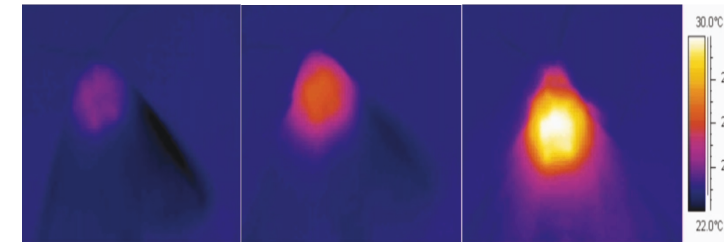
# Act on the problem ► By acting on the flow ► Through the modification of state variables ► Locally



A heat sink transfers thermal energy from a higher temperature device to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction.



Induction cooking uses induction heating to directly heat a cooking vessel, as opposed to using heat transfer from electrical coils or burning gas as with a traditional cooking stove. In an induction cooker, a coil of copper wire is placed underneath the cooking pot. An alternating electric current flows through the coil, which produces an oscillating magnetic field. This field induces an electric current in the pot. Current flowing in the metal pot produces resistive heating which heats the food. While the current is large, it is produced by a low voltage. An induction cooker is faster and more energy-efficient than a traditional electric cooking surface. It allows instant control of cooking energy similar to gas burners. The induction effect does not directly heat the air around the vessel, resulting in further energy efficiencies. Cooling air is blown through the electronics but emerges only a little warmer than ambient temperature.



By Crespo j (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

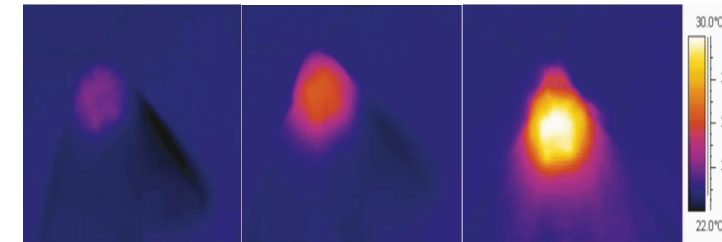
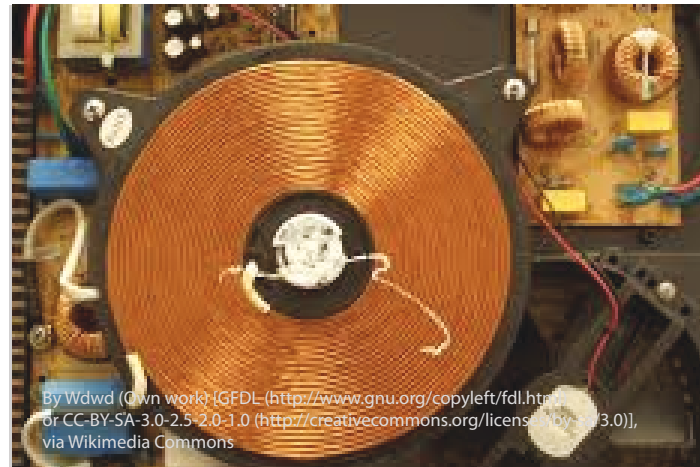
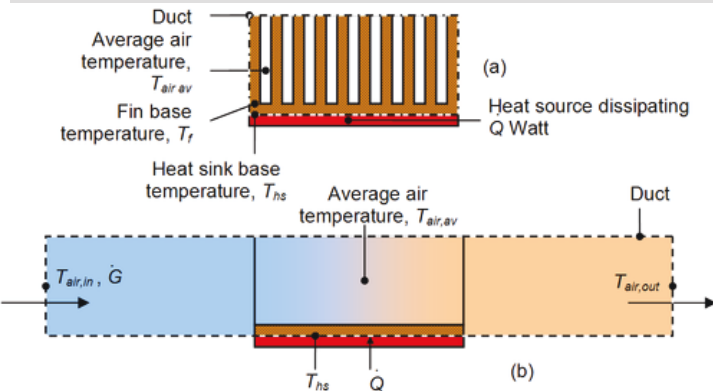
Exogenously heated bumblebees prevent overheating of the thorax by shunting heat into the abdomen. They also regurgitate fluid, which helps to reduce head temperature but has little effect on thoracic temperature.

Temperature increases in the ventrum of the abdomen occurred in steps exactly coinciding with the beats of the ventral diaphragm, and with the abdominal 'ventilatory' pumping movements.

The anatomical counter-current heat exchanger is reduced or eliminated during heat stress by 'chopping' the blood flow into pulses, and the blood pulses are shunted through the petiole alternately by way of a switch mechanism



Act on the problem ► By acting on the flow ► Through the modification of state variables ► Locally



By Crespo j (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

By Mokkie (Own work) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

## RELEVANT PARAMETERS

### Input

$$P = V \cdot I$$

### Output

$$P = \alpha \cdot \mu \cdot S(T_{base} - T_{air})$$

$$P = q \cdot C_P \cdot (T_{out} - T_{in})$$

where:

P=Power

V=Voltage

I=Current

$\alpha$ = Natural convection coefficient

$\mu$ = Fin efficiency

S= Surface area

q= Air flow rate

C<sub>p</sub>= Heat capacity

T= Temperature

## RELEVANT PARAMETERS

### Input

$$P = V \cdot I$$

### Output

$$P = MC_p \frac{dT}{dt} + \frac{k}{e} \cdot A(T - T_{wall})$$

where

MC<sub>p</sub> = Thermal mass

k= Conductivity

A= Contact area

e= Thickness

and T-T<sub>wall</sub> is the output power

## HEAT

$$Q = U \times I \times t$$

where:

Q = Power;

U = Tension;

I = Current;

t = Time.

## HEAT TRANSFER COEFFICIENT

$$\Delta Q = \alpha \times \mu \times S \times (T - T_m) \times \Delta t$$

where:

$\Delta Q$  = Heat exchange;

$\alpha$  = transfer coefficient;

$\mu$ = Efficiency of the material

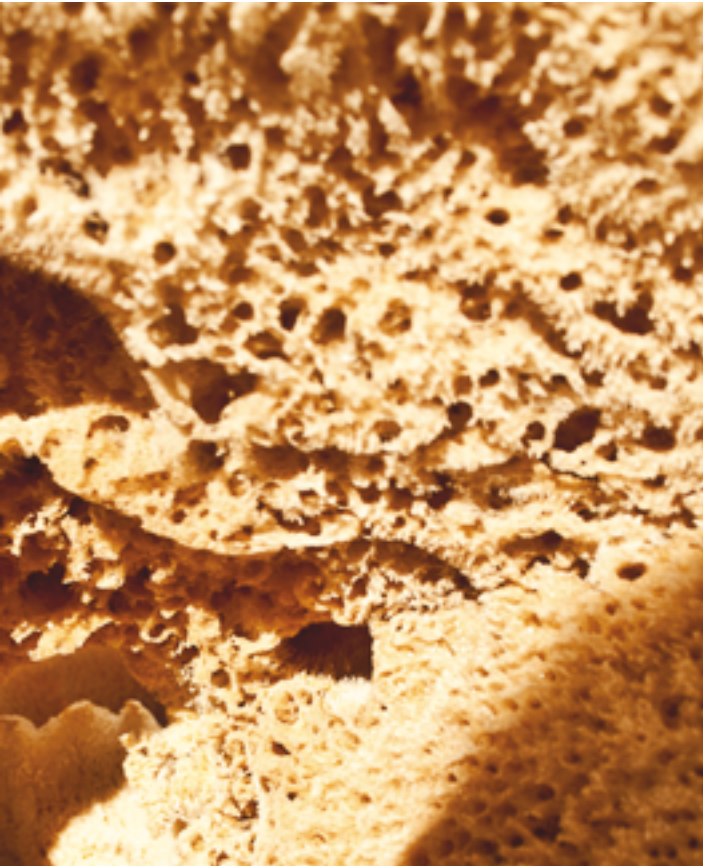
S= Area of the contact surface;

T = Temperature of material;

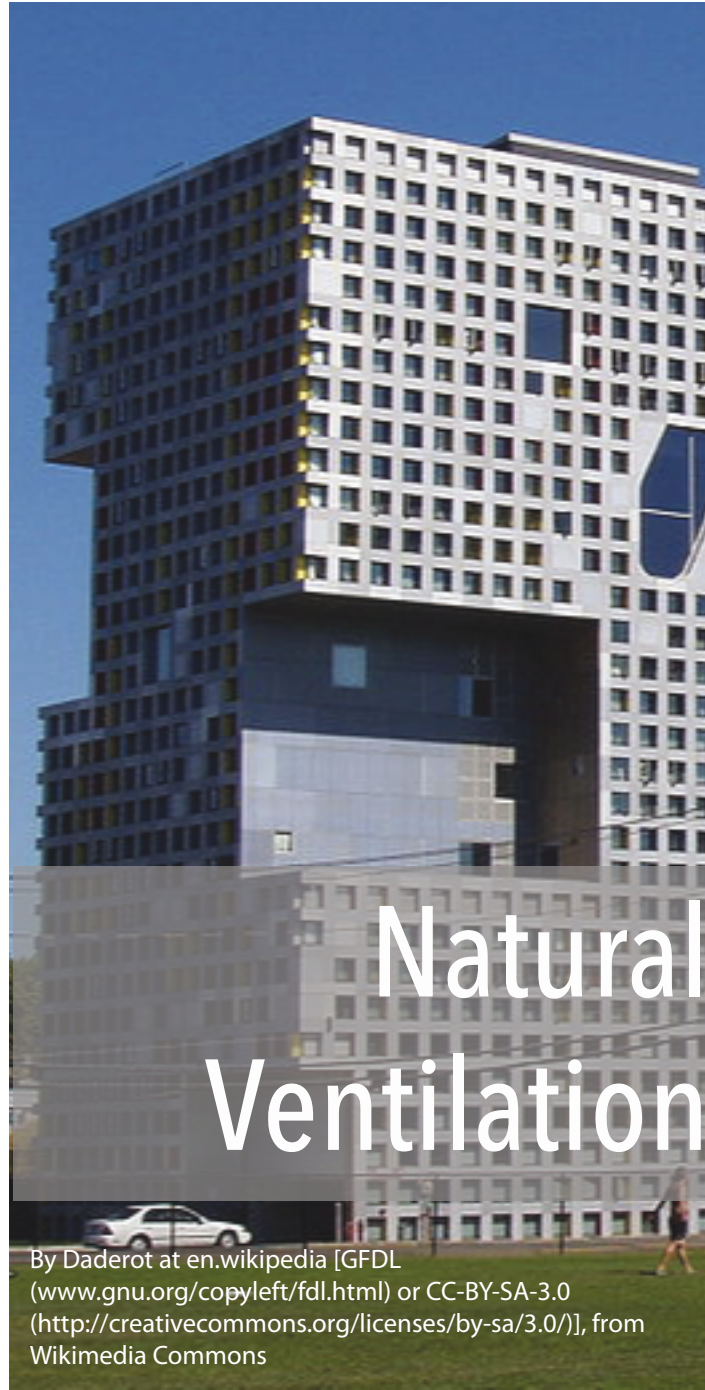
T<sub>m</sub> = Temperature of the environment;

$\Delta t$  = Duration.

Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of materials ► Through porous media or multimaterials



Porous  
Medium



Natural  
Ventilation

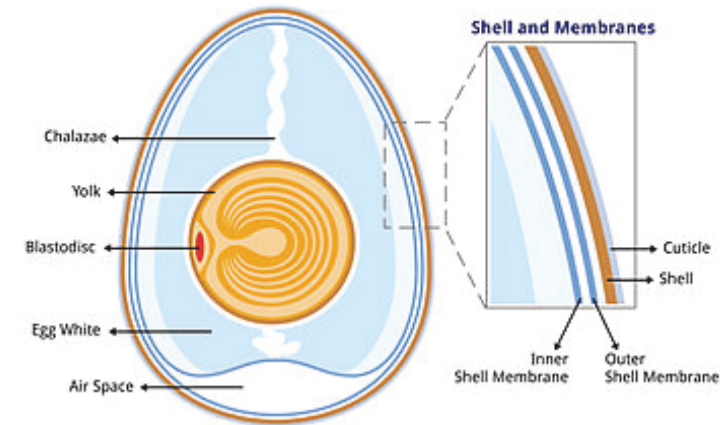
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Bird  
Eggs



Act on the problem ► By acting on the generation/transmission/interaction systems ► Modifying components ► Adapting components ► Through the evolution of materials ► Through porous media or multimaterials



A porous medium (or a porous material) is a material containing pores or voids. The skeletal portion of the material is often called the "matrix" or "frame". The pores are typically filled with a fluid (liquid or gas).

A porous medium is most often characterised by its porosity. Other properties of the medium (e.g., permeability, tensile strength, electrical conductivity) can sometimes be derived from the respective properties of its constituents (solid matrix and fluid) and the media porosity and pores structure.

Often both the solid matrix and the pore network (also known as the pore space) are continuous, so as to form two interpenetrating continua such as in a sponge. However, there is also a concept of closed porosity and effective porosity, i.e., the pore space accessible to flow.

Many modern buildings reject hi-tech environmental solutions in favor of low-tech passive environmental solutions for ventilation, which is achieved through a "porous" building structure. These designs take advantage of the weather conditions, creating a minimal environmental load.

Porosity offers efficient ventilation in numerous directions. The pores act as air channels that capitalize on pressure differences, introducing fresh air in the building and exhausting stale air

By Anatomy\_of\_an\_egg\_unlabeled.svg; de:Benutzer:Horst Frank, SVG code cs:User:-xfi-, text removed by User:Kjoonlee derivative work: Vkkodali (Anatomy\_of\_an\_egg\_unlabeled.svg) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)], via Wikimedia Commons

Eggshell textures are the result of a porous microstructure that regulates the passage of water vapor, respiratory gases, and microorganisms between the inside of the egg and the external world. The eggshell is permeated by thousands of microscopic pores. An ordinary hen's egg has more than 7500 pores, mostly at the blunt end of the egg.

The shells of most avian eggs have simple, straight pore canals that widen slightly toward the openings on the exterior surface.



Act on the problem ▶ By acting on the generation/transmission/interaction systems ▶ Through the modification of components ▶ Globally ▶ Through the segmentation of the structure of the components ▶ By layers



CFRP

"Steinbichler Shearography Honeycomb with CFRP Top Layer Artificial failures that simulate layer- core delaminations Material Top view" by Shearo - Own work.  
Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Steinbichler\\_Shearography\\_Honeycomb\\_with\\_CFRP\\_Top\\_Layer\\_Artificial\\_failures\\_that\\_simulate\\_layer-core\\_delaminations\\_Material\\_Top\\_view.jpg#mediaviewer/File:Steinbichler\\_Shearography\\_Honeycomb\\_with\\_CFRP\\_Top\\_Layer\\_Artificial\\_failures\\_that\\_simulate\\_layer-core\\_delaminations\\_Material\\_Top\\_view.jpg](http://commons.wikimedia.org/wiki/File:Steinbichler_Shearography_Honeycomb_with_CFRP_Top_Layer_Artificial_failures_that_simulate_layer-core_delaminations_Material_Top_view.jpg#mediaviewer/File:Steinbichler_Shearography_Honeycomb_with_CFRP_Top_Layer_Artificial_failures_that_simulate_layer-core_delaminations_Material_Top_view.jpg)



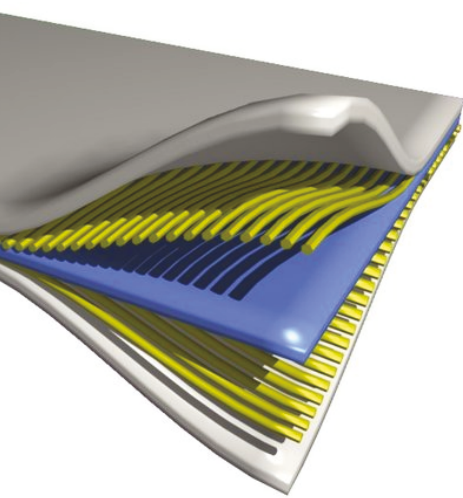
Embody  
Chair

Embody-Chair-Blue by bfi Business Furniture Inc. Licensed under Creative Commons Attribution-Share Alike 2.0  
<https://www.flickr.com/photos/bfionline/3117948393/in/photostream/>



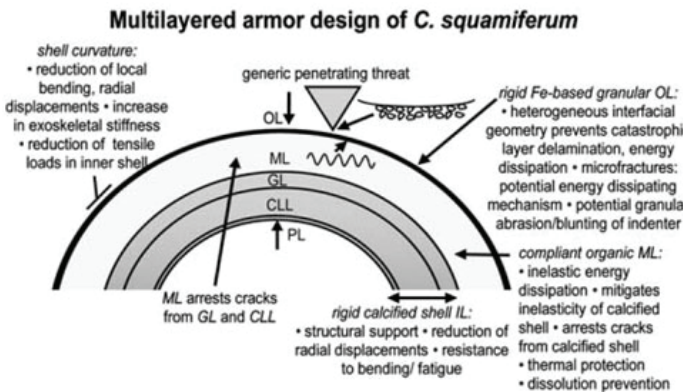
Golden Scale  
Snail

<http://4allll.com/awesomestuff/wp-content/uploads/2014/08/Snail.jpg>



Composite materials such as carbon-fibre-reinforced polymer (CFRP) have become a cornerstone of modern spacecraft production.

Composite components, with optimised strength and rigidity, are manufactured in a standardised manner, typically with 'wet-layup' – where composites are laid down in a mould – followed by 'vacuum bagging' – where a bag layer is applied from which all air is then extracted so this bag precisely hugs the composite surface – and then 'autoclaving' where composites are cooked or 'cured' inside high-temperature, high-pressure chambers.



Yao et al. 2010. Protection mechanisms of the iron-plated armor of a deep-sea hydrothermal vent gastropod. PNAS <http://dx.doi.org/10.1073/pnas.0912988107>

The snail has evolved a tri-layered shell structure consisting of an outer layer embedded with iron sulfide granules, a thick organic middle layer, and a calcified inner layer. This creates a configuration in which the inner compliant layer is sandwiched between two rigid layers.

The unique three-layer structure dissipates mechanical energy, which helps the snails fend off attacks from crabs that squeeze the shell with their claws in an attempt to fracture it..



Embody-Chair-Orange by bfi Business Furniture Inc. Licensed under Creative Commons Attribution-Share Alike 2.0 <https://www.flickr.com/photos/bfionline/3117948393/in/photostream/>

Fabric-over-foam padding has long been the conventional approach to work chair construction. Such padding has insulating properties that prevent conduction of heat away from the body. Foam padding can also impede water vapor transfer from the skin's surface

The Embody chair works around this problem by developing breathable and porous seat and backrest materials that provide comfort and allow conduction of heat and dispersion of moisture away from the surface of the skin.

The porous quality of suspension materials allows for unobstructed moisture dispersion and conduction of heat away from body surfaces that touch the backrest or seat pan.

A more recent development is the Pixelated Support system. It uses both a global and a local spring layer to fit the sitter's body shape. This contoured, layered design allows for air to flow through the layers.